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AN EXAMINATION OF AIRCRAFT AGING IN CANADA

February 1991

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AN EXAMINATION OF AIRCRAFT AGING IN CANADA

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of Transportation Development Centre
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Transport Canada

by

Claude M. Schonberger

February 1991

The contents of this report reflect the views of the author and not necessarily the official view or opinions of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract

This report traces the early history of serious age-related air carrier structural failures and discusses the many facets of structural integrity, including structural evaluation, safety factors, surveillance, and life management, as well as maintenance, repair, and inspection of the aging fleet. It presents a profile of the Canadian fleet, methods of coping with aircraft age, and technology being used to detect or predict aircraft aging, and others conclusions drawn from these discussions.

Random sampling of the Canadian Fleet was accomplished by means of field visits to several large and small air carriers, manufacturers, the Air Transport Association of Canada, and the Institute of Aerospace Research. Airplanes that had aged between 15 and 25 years were considered.

Recommendations are made with respect to aircraft aging and the need for further research in the area. Reference material includes a glossary and appendices, containing checklists for aircraft aging, and a summary of field visits made to large and small air carriers.

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16. Résumé

Ce rapport relate les premiers accidents aériens attribuables à des défaillances structurelles liées à l'âge des aéronefs et traite des divers aspects de l'intégrité structurelle, incluant l'évaluation structurelle, les facteurs de sécurité, le suivi de sécurité et le coût d'entretien sur la durée de vie. Il traite aussi du phénomène de vieillissement et des impératifs de maintenance, de réparations et de contrôles. En outre, il fait le décompte des flottes aériennes au Canada, recense les techniques permettant de lutter contre le phénomène de vieillissement, qu'il s'agisse de techniques préventives ou prédictives, et tire diverses conclusions à partir des arguments présentés.

Les chercheurs ont pris un échantillonnage aléatoire des flottes aériennes du Canada en se rendant chez les transporteurs, petits et grands, dans les avionneries, auprès de l'Association du transport aérien du Canada et de l'Institut de recherches aérospatiales. Les aéronefs pris en compte avaient entre 15 et 25 ans d'âge.

Des recommandations sont formulées, notamment sur la nécessité d'entreprendre de plus amples recherches dans le domaine du vieillissement. En fin de rapport on trouve une partie documentaire comportant un glossaire terminologique et plusieurs annexes, dont une liste de contrôle applicable aux aéronefs vieillissants et une liste des visites rendues aux transporteurs aériens, petits et grands.

17. Mots clés	18. Diffusion
Vieillissement des aéronefs, navigabilité, corrosion, contrôles non destructifs, fatigue structurelle, fissures groupées, programmes de contrôles complémentaires.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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SUMMARY

This project is an investigation into the aircraft-aging problem for the Canadian fleet undertaken as part of the Transportation Development Centre's visiting-expert program.

The introduction discusses recent annual passenger boardings, numbers of registered aircraft in Canada, and fleet status, as well as the major effects of aircraft aging and marketplace decisions to retire aircraft.

Primary problems associated with aging aircraft are discussed, as well as Canada's dependence on the regulator, the manufacturer, and the operator (all of whom have interdependent responsibilities) for the airworthiness of its commercial fleet. Fatigue design objectives are also summarized.

A historical background concerning aircraft-aging documents the early Comet I accidents in the early 1950s, which provided many lessons about fatigue-resistant design of aircraft structures; and the Dan Air B-707 accident in 1977, which resulted in supplemental inspection documents being developed to provide a continual inspection or audit program to ensure safe operation of older airplanes that have exceeded their economic design life objective.

The Aloha accident is discussed. This concerned the failure of a maintenance program to detect the presence of significant disbonding and failure damage, which ultimately led to failure of a lap joint and separation of the fuselage upper lobe.

Aircraft design requirements concerning safe-life, fail-safe, and damage tolerant concepts and their effects on structural airworthiness are discussed.

Aircraft-aging elements such as fatigue, crack growth, disbonding, corrosion, and multiple-site damage are identified and assessed as failure mechanisms.

The section on structural integrity and surveillance covers the technology needed to trace failure mechanisms and to ensure a long and safe structural life.

The discussion of maintenance, inspection, and repair provides a review and update of these practices and notes a need for data-base, repair and modification practices, corrosion detection and prevention, and new NDI systems technology to bring these fields up-to-date.

A general discussion of human factors follows, covering task analysis, training, equipment and environmental design, job performance, and selection, placement, and motivation of personnel. Technology that is now in place or planned for the future to predict the greying of the fleet is discussed.

Service difficulty reports, as a means for allocating resources, detecting airworthiness trends, and identifying specific aircraft-aging problems, are covered.

The shortage of aviation field inspector staffing and structural maintenance engineers is covered, and supported by a statistical sketch of present Transport Canada staffing.

A Canadian fleet profile is depicted with charts on air carrier and commuter/regional air carrier fleets.

A discussion of supplemental inspection documents, service bulletins, airworthiness directives, and work in progress in Canada and the United States concerning aircraft aging is used to indicate how Canada is coping with the problem.

The report ends with conclusions and recommendations drawn from the above research. Recommendations include such subjects as improvements in the service difficulty reporting systems, airworthiness inspection, training and experience, development of a human factors handbook, participation in aging-aircraft seminars and technical gatherings, and general supports of the service difficulty reporting program.

Reference material includes reference documents and bibliography, a glossary of aircraft-aging terms, and eight appendices.

SOMMAIRE

Cette recherche portant sur le phénomène de vieillissement des flottes aériennes au Canada a été entreprise dans le cadre du programme des experts invités lancé par le Centre de développement des transports.

L'introduction donne des statistiques récentes sur le nombre de personnes transportées et le nombre d'aéronefs immmatriculés au Canada, fait le point sur l'avancement des travaux dans ce domaine ainsi que sur les principaux effets du vieillissement des aéronefs et des décisions prises en vue de les retirer du service actif.

On y aborde les grands problèmes associés au phénomène de vieillissement et on y discute le fait que, en matière de certification de la navigabilité des aéronefs civils, l'État doit faire confiance au législateur, au constructeur et à l'exploitant (leurs responsabilités en la matière étant étroitement reliées). Également, les règles de calcul à la fatigue adoptées y sont récapitulées.

Le rapport fait un rappel historique des accidents aériens qui ont défrayé la chronique au début des années 1950 et qui étaient liés à l'âge des aéronefs. Il s'agit en l'occurrence des accidents des Comet I, dont on a compris par la suite que la cause avait été la rupture en fatigue de la cellule. Il rappelle également l'accident d'un B 707 de Dan Air, survenu en 1977. Cet accident a eu pour effet l'élaboration de programmes de contrôles complémentaires visant les aéronefs qui ont dépassé le nombre total de cycles prévus à leur égard, le but de ces programmes étant de pourvoir à la maintenance des aéronefs, et à leur sûreté au-delà de ce total.

Le rapport rappelle en outre le cas du B 737 d'Aloha Airlines, alors que la rupture d'un joint à recouvrement a provoqué le déchirement et l'arrachement de toute la partie supérieure avant du fuselage. Cette rupture a été la conséquence de décohésions à l'interface des panneaux, le programme de maintenance n'ayant pas réussi à les détecter à temps.

Il traite des prescriptions relatives à la durée de vie sûre, à la sécurité intrinsèque, à la tolérance aux dommages et à l'effet de ces facteurs sur la résistance des cellules d'aéronefs.

Il identifie et analyse par la mécanique de la rupture les facteurs de vieillissement en jeu : fatigue, propagation des fissures, décohésions, corrosion et dommages multiples.

La partie du rapport traitant de l'intégrité structurelle et de son suivi rappelle la technologie à mettre en oeuvre pour identifier les mécanismes de rupture et en prévenir les effets.

Le rapport fait un tour d'horizon des procédures récentes relatives à la maintenance, au contrôle et à la réparation des aéronefs. Il met en évidence le besoin d'une base de données appropriée, de procédures de réparation et de modification, de moyens permettant la détection et la prévention de la corrosion et de méthodes de contrôle non destructif permettant de les valider.

Il aborde ensuite la question des facteurs ergonomiques : analyse des tâches, formation, conception des matériels, organisation du milieu environnant, rendements au travail, sélection, affectations et motivation du personnel.

Il analyse la technologie actuelle ou future permettant de tenir compte du facteur de vieillissement d'une flotte aérienne.

Il propose d'utiliser les rapports de difficultés en service pour assurer une bonne affectation des ressources, mettre en évidence l'évolution dans l'aptitude d'une flotte à assurer un service sûr et identifier les problèmes de vieillissement qui risquent de compromettre ce service.

Il discute de la pénurie chez Transports Canada d'inspecteurs itinérants et de spécialistes en maintenance des cellules, et donne des statistiques récentes à l'appui.

Il fait le décompte des flottes aériennes du Canada en distinguant entre transporteurs nationaux et transporteurs régionaux.

Il fait le point sur les programmes de contrôle complémentaires, les bulletins de service, les directives concernant la navigabilité ainsi que les travaux sur le vieillissement des aéronefs au Canada et aux États-Unis et ce, pour expliquer ce qui se fait au Canada dans le but de résoudre ce problème.

Le rapport tire des conclusions et formule des recommandations. Parmi ces dernières, mentionnons la proposition d'améliorer la manière dont sont signalées les difficultés en service et les recommandations concernant les contrôles de navigabilité, la formation, l'expérience requise, l'élaboration d'un manuel sur les facteurs ergonomiques, la participation aux colloques et ateliers techniques sur le vieillissement des aéronefs et l'appui à donner au programme de rapports des difficultés en service.

En fin du rapport, on trouve une partie documentaire comprenant une bibliographie, un glossaire terminologique et huit annexes.

TABLE OF CONTENTS

	PAGE
GLOSSARY OF TERMS	xv
1. INTRODUCTION	1
2. BACKGROUND	4
2.1 Comet Accident	4
2.2 Dan Air Accident	6
2.3 Aloha Accident	10
2.4 Air Canada Incident	15
3. AIRCRAFT DESIGN REQUIREMENTS	17
3.1 Safe-Life Concept	17
3.2 Fail-Safe Concept	17
3.3 Damage-Tolerant Concept	18
4. AIRCRAFT AGING DEFINED	19
4.1 Fatigue	19
4.2 Crack Growth	19
4.3 Disbonding	20
4.4 Corrosion	20
4.5 Multiple-Site Damage	23
5. STRUCTURAL EVALUATION	24
5.1 Structural Safety Factors	24
5.1.1 Fatigue Analysis/Test	24
5.1.2 Proof Pressure Test	25
5.2 Structural Surveillance	26
5.3 Structural Life Management	26
6. MAINTENANCE/INSPECTION/REPAIR	27
6.1 Canadian Air Carrier Maintenance Costs	28
6.2 In-House vs Outside Maintenance Costs	29
6.3 Maintenance Costs Analysis	31
6.4 Inspection and Inspectors	32

TABLE OF CONTENTS (Cont'd)

PAGE

7. HUMAN FACTORS 33

8. DETECTION/PREDICTION OF AIRCRAFT AGING 34

8.1 Service Difficulty Reporting System 34
8.2 Corrosion Detection 36

9. CANADIAN FLEET PROFILE 42

10. COPING WITH AIRCRAFT AGING IN CANADA 43

10.1 Supplemental Inspection Documents 43
10.2 Service Bulletins and Airworthiness Directives 43

11. CONCLUSIONS 46

12. RECOMMENDATIONS 47

13. REFERENCE MATERIAL 48

13.1 List of References 48
13.2 Bibliography 49

APPENDICES

Appendix A -Aging Aircraft Activities Status Report A-1
Appendix B -Aging Aircraft Activities Update B-1
Appendix C -Air Carrier SID Compliance C-1
Appendix D -Aging Aircraft Sampling Evaluation D-1
Appendix E -Airworthiness Directives E-1
Appendix F -Field Visit Reports F-1
Appendix G -Aircraft Aging Check Lists G-1
Appendix H -Leased Aircraft in the United States H-1

LIST OF FIGURES

		PAGE
1.	Probable Failure Origin of Jan 10, l954 Comet Flight	5
2.	Probable Failure Origin of Comet I Test Aircraft	5
3.	Typical Window Corner Stresses, Comet I	6
4.	B-707/300-400 Stabilizer Cracking	8
5.	Crack Growth Data	8
6.	Ground Spoiler Effect On Stabilizer Stresses	9
7.	Typical Flight Stress Profile	9
8.	General View, Aloha B-737, Left Side	11
9.	General View, Aloha B-737, Right Side	11
10.	B-737 Lap splice configuration, showing cold/hot bonding	13
11.	Relationship of cyclic stress to cycles of stress	19
12.	Types of Corrosion	21
13.	Effect of Corrosion on Fatigue	21
14.	Contributing Causes of Corrosion	22
15.	Most Susceptible Areas of Corrosion	22
16.	Airframe Loads	24
17.	Service Bulletin and Airworthiness Directive Actions	44

LIST OF TABLES

		PAGE
1.	Fatigue Design Objectives	3
2.	Repeat Check Intervals In Flight Cycles	14
3.	Comparison of Operating Expenses and Maintenance Costs, U.S. Air Carriers	28
4.	Comparison of Operating and Maintenance Costs	29
5.	Comparison of Outside Maintenance Work To Total Direct Maintenance, U.S. Air Carriers	30
6.	Comparison of Outside Maintenance To Total Direct Maintenance, Total Canadian Air Carriers, and Level I and Level II Carriers	30
7.	U.S. Maintenance Cost Analysis	31
8.	Canadian Maintenance Cost Analysis	31
9.	Comparison of Total Annual SDR Reports	37
10.	Age - Canadian Air Carrier Fleet, March 1989	38
11.	Age - Canadian Air Carrier Fleet, January 199l	38
12.	Age of Fleets of Major Canadian Air Carriers, March 1989 and January 1991	39
13.	Average Age of U.S. Manufactured Aircraft In World-wide Use	39
14.	Projected U.S. Manufactured Aircraft 20 Years Old or More, 1989, 1995, and 2000	40
15.	Age Distribution of U.S. Airline Fleet	40
16.	Commuter Aircraft In U.S.	41
17.	Selected Canadian Charter and Regional Airlines Aircraft, 15 Years or More of Age	41

GLOSSARY

AIRWORTHINESS DIRECTIVE (AD):

Directives issued in respect to aeronautical products either to correct unsafe conditions or to correct situations where an aeronautical product does not comply with the basis of type approval affecting its airworthiness. They are issued to maintain aeronautical products in a fit and safe state for flight. They are standards of airworthiness and are published pursuant to section 211(1) of the Minister of Transport's Air Regulation.

BONDING:

Structurally joining parts by adhesives, especially adhesives cured under elevated temperature and/or pressure.

"C" CHECK:

A system and component check, airworthiness evaluation. The maintenance planning document divides aircraft maintenance into four series of checks with specific recurring frequency. The "C" check interval is usually around 3,000 to 5,000 flight hours and is based on a flight hours interval.

CORROSION:

Process of eating or wearing away gradually, as if by gnawing, especially by chemical action or the chemical deterioration of a metal.

CRACK PROPAGATION:

Progressive growth in the length of a microscopic crack in a stressed metal part, without deformation of structure, until remaining material suddenly breaks.

CYCLES:

One complete cycle, that is, start-up, taxi, takeoff, climb pressurization, cruise, possibly combat, descent depressurization, landing, thrust-reverse, taxi, & shutdown.

"D" CHECK:

A structural inspection to determine airworthiness; a heavy maintenance level check usually accomplished around each 15,000 hours on the aircraft and based upon a flight hours interval. The aircraft is usually completely torn down.

DAMAGE TOLERANCE CONCEPT:

Structure designed to continue to bear normal in-flight loads after failure (through fatigue, external damage or other cause) of any member.

DESIGN LIMIT LOAD:

Specified limit load below which structural member or part is designed not to fail, usually expressed as probable maximum limit load, unfactored.

DISBONDING:

The separation of parts previously bonded in manufacture, especially the separation of layers making up the skin of an aircraft.

DOUBLER:

Additional layer of sheet or strip to reinforce structural joints.

ECONOMIC DESIGNED LIFE OBJECTIVE:

The initial safe lifetime of an aircraft designed at time of manufacture, usually determined by the number of total cycles and the number of total flight hours accomplished on the structure. These limits are sometimes reverified by "proof testing" of the airframe and life or use continued by means of a Supplemental Structural Inspection Document.

FACTOR OF SAFETY:

1. Factor by which limit load is multiplied to produce load used in design of aircraft or part; intended to provide margin of strength against loads greater than limit load, and against uncertainties in materials, construction, load estimation and stress analysis.
2. Ratio of ultimate strength to actual working stress or maximum permissible stress in use of material component.

FAIL-SAFE CONCEPT:

Normally, structural design, rather than system, technique in which no crack can cause catastrophic failure of whole structure but is allowed to occur and be detected.

FATIGUE:

Weakening or deterioration of metal or other material under load, especially repeated cyclic load; causes cracks and ultimately failure.

FATIGUE FAILURE:

Failure of a component under the action of repeated stress; occurs after an interval of cyclic loading.

FAYING SURFACE:

Overlapping of adjoining skin surfaces with edges exposed to airstream or to water.

FLAPPING:

Ensuring pressure relief by means of a design in cylindrical pressurized shells to permit longitudinal cracks to turn in a circumferential direction, thus allowing pressure relief before catastrophic failure.

FLIGHT CYCLE:

Sequence of operations and conditions, different for airframe, propulsion and each system or equipment item, which together make up one flight.

FLIGHT LOADS:

Loads or stress on an airframe while in flight; associated with takeoff loads, gust loads, maneuvering loads, thrust loads, and pressurization loads.

GUST LOAD:

The load condition imposed on an airplane by flying into vertical or horizontal air currents.

HANDS-ON INSPECTION:

With human(s) interfacing with system. Actually looking at corrosion or fatigue failure rather than looking at the paperwork involving same.

HUMAN FACTORS:

The study of psychophysical, psychological, and physiological variables which affect human performance in an operational system.

INITIAL SERVICE DATE:

Date at which the model was first put into service after manufacture.

LAP JOINT:

One sheet edge overlapping its neighbour. In riveting, a joint in which the two edges of the parts to be riveted overlap each other and the rivets are placed in the overlapping portion.

LIMIT LOAD:

The calculated maximum load that an aircraft member or part will experience in service.

LONGERON:

A fore-and-aft member of the framing of an aircraft fuselage or nacelle; usually continues across a number of points of support.

MAINTENANCE COSTS:

Expenses, both direct and indirect, incurred in the repair and upkeep of property and equipment required to meet operating and safety standards.

MAINTENANCE PLANNING DOCUMENT:

Document dealing with maintenance developed by the airframe manufacturer in conjunction with the regulatory agency that establishes the procedure for maintaining the aircraft.

MARGIN OF SAFETY:

Percentage or ratio by which ultimate failing load of the component exceeds the design limit load.

MULTIPLE SITE DAMAGE:

Group of small cracks, sometimes grouped around rivet holes, that originate about the same time around similar structured details near one another. After a period of time, they may consist of a large crack growing toward a group of small cracks.

MULTIPLE LOAD PATH:

Identified with redundant structures in which, with the failure of individual elements, the applied loads would be safely distributed to other load-carrying members.

NDE/NDI/NDT:

Non-Destructive Evaluation (Inspection & Testing) includes methods and diagnostic tools for investigating the quality, integrity, properties and dimension of materials, parts, and structures without causing changes in any characteristic that will adversely affect the reliability or serviceability of the material, part, structure, or system being examined. These methods include, but are not limited to, dye-penetrant, magnetic particle, eddy current, ultrasonic and radiographic techniques.

NPRM:

Notice of Proposed Rule Making, which allows publication of a proposed rule and official comment by interested parties before the final rule is implemented.

OPERATING EXPENSES:

Expenses incurred in the implementation of air transportation. It includes direct aircraft operating expenses as well as ground and indirect operating expenses.

PRIMARY STRUCTURE:

A structure whose failure at any point would imperil safety.

PRINCIPAL STRUCTURAL ELEMENTS:

(PSE) are those elements of primary structure that contribute significantly to carrying flight, ground, and pressurization loads, and whose failure could result in catastrophic failure of the aircraft.

PROOF PRESSURE TEST:

Testing a vessel or piece of equipment by means of applying air pressure as a rapid way to assess the integrity of the structure. For example, solid rocket motor cases were proof pressure tested as part of acceptance procedure. The test is used in both military airframes and in air carrier pressurized airframes.

SAFE-LIFE:

Basic design and certification philosophy for a primary structure; whether or not there are redundant load paths or fail-safe provisions, a total acceptable life (flight time) is published in the flight manual and the relevant structure must then be replaced, even if no crack is visible.

SERVICE BULLETIN:

Information issued by manufacturers of aircraft engines or components detailing maintenance procedures that will enhance safety or improve performance of products. These procedures are not mandatory.

SERVICE DIFFICULTY REPORTS (SDR):

The SDR system is an international comprehensive arrangement for the collection, organization, and dissemination of information on specific problems occurring in aircraft systems and components. Reports are obtained from all segments of the aviation industry on significant failures, malfunctions, and defects in aeronautical products that could adversely affect the safety of flight.

SINGLE LOAD PATH:

Where the applied loads are eventually distributed through a single member, the failure of which would result in the loss of the structural integrity of the component involved.

SMART RECORDER:

An on-board microprocessor-based system capable of analyzing and making decisions on what data is meaningful to store for post-flight evaluation. Used in load analysis.

SSID PROGRAM (SSIP):

Originated in the early 1980s, it is a process that allows a proactive approach to maintenance problems through early detection stemming from lead aircraft inspections. It provides a continuing structural integrity program to ensure safe operation of older aircraft throughout their operational life.

STRESS CORROSION:

Metal cracking due to residual stress from manufacturing processes or concentrated stresses caused by flight loads and/or poor design.

STRINGER:

Longitudinal member (i.e., in fuselage more or less aligned with longitudinal axis and in wing and tail surfaces more or less perpendicular to this axis) that gives airframe its shape and provides basis for skin.

STRUCTURAL INTEGRITY:

Identifying, evaluating, and developing improvements in maintenance, inspection and repair to assess failure mechanisms such as multiple-site cracking, corrosion, fatigue, and disbonding.

SUPPLEMENTAL INSPECTION DOCUMENT (SID):

An addition to the basic, complete maintenance program for an aircraft. It identifies principal structural elements whose failure could cause the loss of the aircraft and is mandated by the regulators for operating an aircraft beyond the economic design life.

TOGAA:

Technical Oversight Group on Aging Aircraft.

ULTIMATE FACTOR OF SAFETY:

Number by which limit (or proof) load is multiplied to obtain ultimate load; purely arbitrary factor of safety, usually varying from 1.5 to 2, representing best humanly attainable compromise between economic structure weight and aircraft that will not break.

ULTIMATE LOAD:

Greatest load that any structural member is required to carry without breaking; load at which it may legally be on the verge of breaking. Usually, limit load x UFS.

1. INTRODUCTION

One U.S. government official has labelled aircraft aging as "...the quintessential safety issue for aviation."[1]

Obviously, aircraft require increased attention and maintenance as they get older. Aircraft age can be measured by the passage of time, but, realistically, we use such criteria as number of flights or cycles to measure aircraft age. As an aircraft accomplishes a flight, loads are put on the airframe. Pressurization and depressurization of the cabin place stress on the skin and structure. Over a period of time, as these cycles accumulate, this expansion and contraction of the metal results in fatigue and cracks in the metal. When you add the phenomenon of corrosion to these fatigue cracks, you have two of the main contributors to mechanical failure.

A system that will ensure structural integrity of an aging airframe requires repairs or modifications at intervals necessary to maintain airworthiness. Because of the demand for aviation services and because new aircraft ordered today by the transport industry will cost exorbitant sums and will require approximately 3-5 years for delivery, we will, of necessity, continue to use older aircraft in our air carrier network. With the efforts towards deregulation, the revenue losses caused by higher fuel expenses, and the inability of air carriers to purchase new equipment, the older airframes are being used beyond their economic design life objectives.

Aircraft aging is not only a Canadian problem but an international one, because the laws of physics know no international boundaries. Accordingly, the Transportation Development Centre of Transport Canada has undertaken this project to ascertain the extent of the aircraft-aging problem in Canada and to determine just where the Canadian air carrier fleet stands internationally and how important it is for Canada to plan for the long term.

Efforts have been made to gather and assess data, and to recommend steps to improve the Canadian air carrier fleet. This report is the culmination of those efforts.

The latest revenue figures from Statistics Canada indicate that in 1990 there were 24,389,000 passenger boardings in Canada involving a total commercial fleet of approximately 3,389 air carrier aircraft. Of these passengers, 23,066,000 flew in scheduled service and 1,323,000 flew in chartered service.

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[1] Chairman James Oberstar, D-Minn, U.S. House Public Works and Transportation Aviation Subcommittee in an interview with Air Safety Magazine, Vol. 4, No. 48, 3 January 1991.

There are approximately 29,000 civil aircraft registered in Canada, which is approximately one aircraft per thousand population, or the second largest aircraft fleet in the western world. Last year, approximately 1,500 aircraft over 4,500 kg (9,900 lbs) were more than 20 years old. The "geriatric" airplane problem is at our doorstep and will get worse before it gets better.

Aircraft are designed today for an economic service life of approximately 20 years, covering some 50,000 flight hours and 50 to 75,000 pressurization cycles. However, once these objectives are reached, the aircraft cannot be scrapped, as such a policy would cause air carriers tremendous hardship and would disrupt passenger activity.

The major effects of aircraft age are involved in the pressurization process whereby the skin of the airframe is stretched. Of course, flight loads, flight hours of operation, years of operation, and the climatic conditions in which the airframe operates are other aspects that must be considered in the aging cycle.

In the past, decisions by air carriers to retire aircraft have largely been driven by marketplace considerations and are usually based upon some or all of the following: noncompetitive operating costs, noncompetitive performance, excessive fuel costs, noncompetitive technology, and noise constraints.

Today, fatigue and corrosion are the primary problems associated with aging aircraft. Corrosion is a function of time, material, and environment, while fatigue is a function of flight hours and, most directly, flight cycles.

The fundamental issue in aircraft aging is the airworthiness assurance of the Canadian commercial fleet. The basic responsibility for this airworthiness lies with three groups: the regulators, the manufacturers, and the operators, whose responsibilities are interdependent. Presently, all three groups are working together, internationally, to improve the collective understanding of aircraft aging, and are taking action to ensure flight safety.

Table 1 depicts the economic design life objective for most of the large air carrier aircraft operating in Canada.

	AIRCRAFT MODEL	INITIAL SERVICE DATE	ECONOMIC DESIGN LIFE OBJECTIVE	
			FLIGHTS	HOURS
BOEING	B-707	Sept-1958	20,000	60,000
	B-720	July-1960	30,000	60,000
	B-727	Feb-1964	60,000	50,000
	B-737	Feb-1968	75,000	51,000
	B-747	Jan-1970	20,000	60,000
DOUGLAS	DC-8	1959	25,000	50,000
	DC-9	1965	40,000	104,000
	MD-80	1980	50,000	50,000
	DC-10-10	1971	42,000	42,000
	DC-10-30/40	1972	30,000	60,000
LOCKHEED	ELECTRA	1959		
	L-188	1972		
	L-1011	1972		
AIRBUS	A-300-B4	May-1974	36,000	60,000
	A-310	Apr-1983	35,000	60,000
	A-300-600	Apr-1984	30,000	67,500
	A-320	Apr-1988	48,000	60,000
	A-340	May-1992*	20,000	30,000
	A-330	Sep-1993*	40,000	60,000

* Estimated

Table 1. Fatigue Design Objectives

2. BACKGROUND

2.1 Comet

Following World War II, a number of new designs, particularly in jet aircraft, were put into service. The first commercial jet liner, the DH-106 Comet I, was put into service by British Overseas Airways (BOAC) on May 2, 1952. The Comet cabin pressurization differential was almost twice that of any other transport category aircraft, which permitted the airplane to climb to greater altitudes and thus allowed increased range and efficiency. On January 10, 1954, at approximately 10:50 a.m., a Comet jet liner, G-ALYP of BOAC, en route from Singapore to London, crashed in the Mediterranean about 20 minutes after leaving Rome, Italy, on the last stage of its flight to London. All the 29 passengers and crew of six were fatally injured. The disaster occurred off the west coast of Italy between the islands of Elba and Monte Cristo and was witnessed by the crews of 2 Italian fishing vessels. These witnesses heard G-ALYP's engines above the clouds, then heard three explosions, very quickly one after the other. All was quiet, then they saw silver things fall or flash out of the clouds, followed by black smoke. No distress signals were heard. The aircraft had flown 3,680 hours and had experienced 1,286 pressurization cycles.

BOAC immediately suspended all Comet services and after a technical investigation and some 50 mechanical modifications had been made on all Comet aircraft, passenger-carrying services were resumed by Comets on March 23, 1954.

On April 8, 1954, just 16 days after resumption of Comet service, another Comet disintegrated in the air at approximately 35,000 feet and crashed into the sea of Naples, Italy. This aircraft was on a flight from Rome to Cairo. At the time of the crash, the airplane had flown 2,703 hours and had experienced 903 pressurized flights.

The investigation of the first Comet I accident on January 10, 1954, concerned examination of the cabin structure removed from the sea near Elba. It confirmed that the primary cause was a pressure cabin failure or rupture due to fatigue, the origin of which was at the right-hand aft corner of a rear automatic direction finder (ADF) window on top of the aircraft (see Figure 1). Earlier, in April of 1954, it was decided that a repeat loading test of the pressure cabin on Comet I was needed. Another Comet I that had made 1,231 pressurized flights was removed from service and the test was conducted in a tank of water to minimize damage in the event of failure. After 1,826 more test pressurizations, for a total of 3,057, a failure occurred in the under-water test airplane pressure cabin. Examination of the test failure proved evidence of fatigue. The failure origin was at the aft lower corner of the forward escape hatch (see Figure 2).

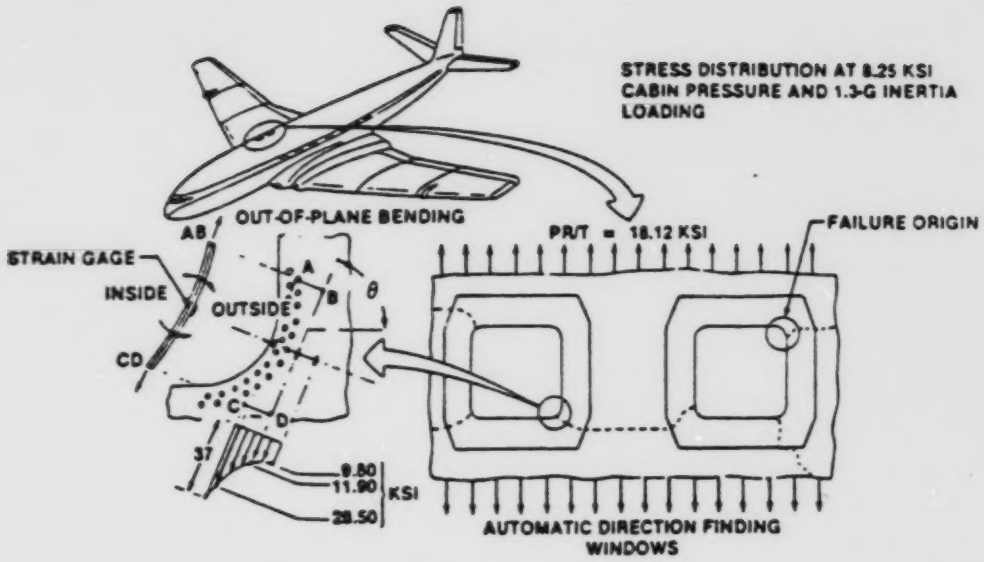

Figure 1 - Probable failure origin of January 10, 1954 Comet flight. (Reference 1.)

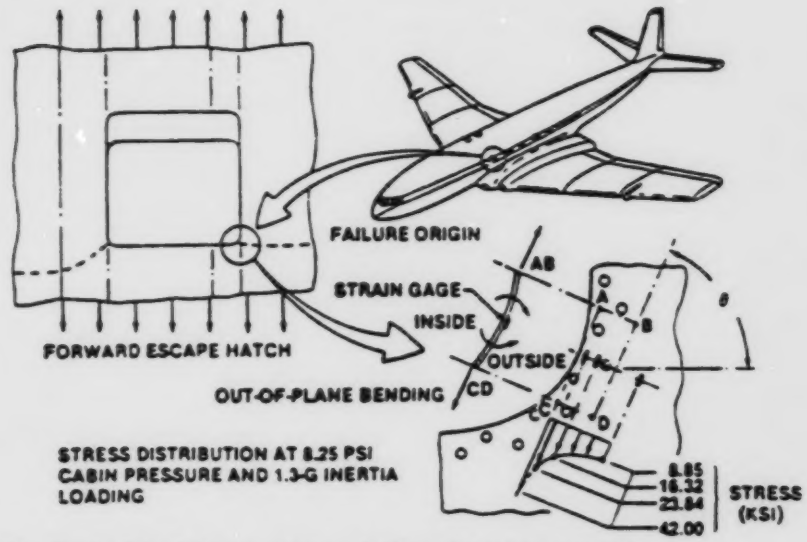

Figure 2 - Probable failure origin of Comet I test aircraft. (Reference 1.)

By the use of strain gages placed at a number of escape hatch and window cutout corners of the fuselage, stress distributions on the outside of the fuselage could be determined, after a cabin pressure of 8.25 psi was loaded. The highest stress was recorded at the upper forward corner of the forward ADF window between frames 24 and 25 as shown in Figure 3. The peak stress of 45.7 ksi represented 70 percent of the ultimate strength capability of the skin material.

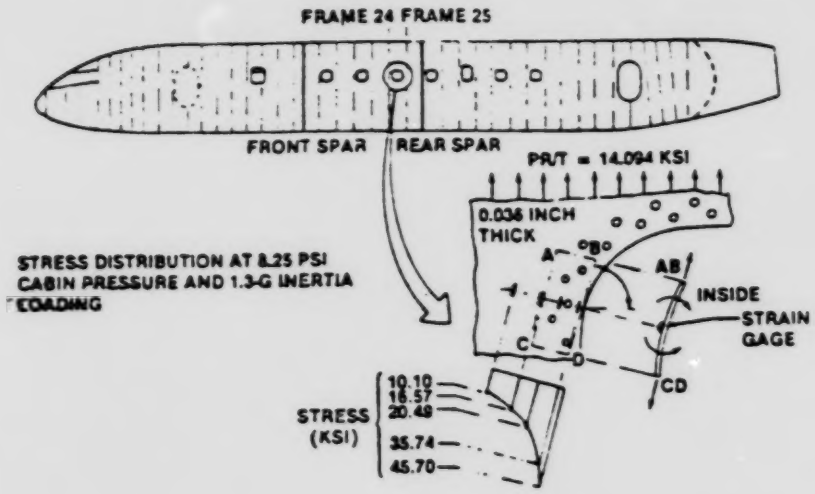

Figure 3 - Typical window corner stresses - Comet I (Reference 1.)

In spite of the tragic consequences of the Comet accident, the subsequent investigation became a valuable learning experience concerning proof-pressure testing and considerable knowledge was garnered from the inquiry.[2]

2.2 Dan-Air Accident

One of the first failures, a milestone in the history of aircraft structures, if not the first aircraft accident involving the aging jet problem, was the Dan-Air Services, Ltd., Boeing

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[2] An excellent discussion of the Comet accidents appears in Thomas Swift's lecture:"Damage Tolerance In Pressurized Fuselages," presented at the 14th Symposium of the International Committee on Aeronautical Fatigue (ICAF) New Materials and Fatigue Resistance Aircraft Design, held at Ottawa, Canada, June 10-12, 1987.

707-321c, G-BEBP, which crashed approximately two miles short of the runway 10 threshold at the Lusaka International Airport, northeast of Lusaka, Zambia, on May 14, 1977. All five crew members and one passenger received fatal injuries.

Eyewitnesses on the ground observed G-BEBP established on what appeared to be a normal approach and saw a large portion of aircraft structure separate in flight. The aircraft then pitched rapidly nose down and dove vertically into the ground from a height estimated to be about 243.84 m (800 feet) in a 50-degree dive, striking the ground and catching fire.

Investigation of the wreckage indicated that the right tailplane had separated at a fatigue failure of the top chord of the rear spar at a point approximately 36 cm (14.17 inches) outboard of the root attachment pin (See Figures 4 & 5). The separation occurred during a manually flown approach, in daylight and in good weather, and shortly after the selection of 50 degrees full landing flaps, a time when maximum horizontal stabilizer flight loads were experienced with the aircraft in the landing configuration, leading-edge flaps extended, and the landing gear down (See Figures 6 & 7).[3]

The investigation indicated that G-BEBP had been manufactured in 1963 and was one of the first aircraft off the B-707-300c series convertible passenger/freighter production line. Since manufacture, it had been operated in the passenger-carrying role of Pan American Airways, registered as N-765PA. After it was withdrawn from service in March, 1976, it was put into storage in Florida. In June of 1976, it was flown to the United Kingdom where it went through a modification and overhaul program at the Dan-Air engineering facility prior to issue of a United States Export Certificate of Airworthiness, which was the basis for the issue on October 14, 1976 of a United Kingdom Certificate of Airworthiness in the Transport Category (Passenger). The records indicate that the aircraft had not been involved in any previous accident and there was no record of it having been involved in any incidents which might have affected the aircraft's structure. It had been established that both the horizontal stabilizers on the aircraft at the time of the accident were those fitted at the time of manufacture.

At the time of the accident, G-BEBP had a total of 47,621 airframe hours and a total of 16,723 cycles or landings. It had accumulated 1,649 flight hours and 438 landings since issue of the United Kingdom Certificate of Airworthiness. The estimated gross weight at time of the accident was 111,030 kg (244,779 lbs.), well below the maximum allowable landing weight of 112,039 kg (247,003 lbs.). The detailed investigation of this accident was confined primarily to the stabilizer and rear fuselage structure to determine (1) the reason for the origin of the fatigue failure, and (2) why the failsafe structure in the rear spar had failed to carry the flight loads once the top chord had fractured as a result of

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[3] The investigation data is from the British Department of Trade, Accident Investigation Branch, accident report.

707-300/400 Stabilizer Cracking

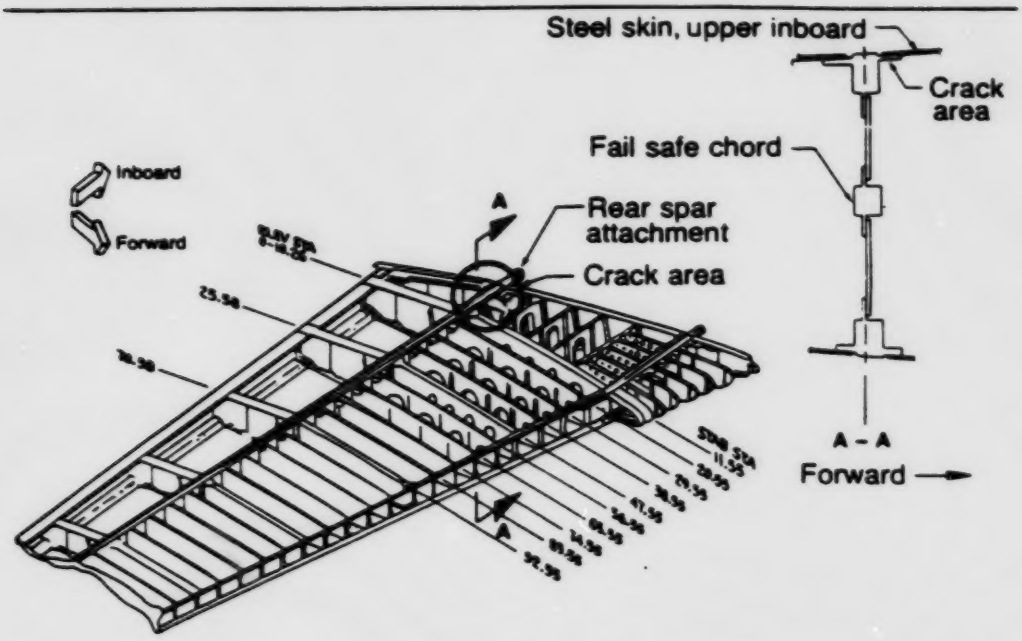

Figure 4 - 707-300/400 Stabilizer cracking (Reference 2.)

Crack Growth Data

Rear Spar Upper Chords

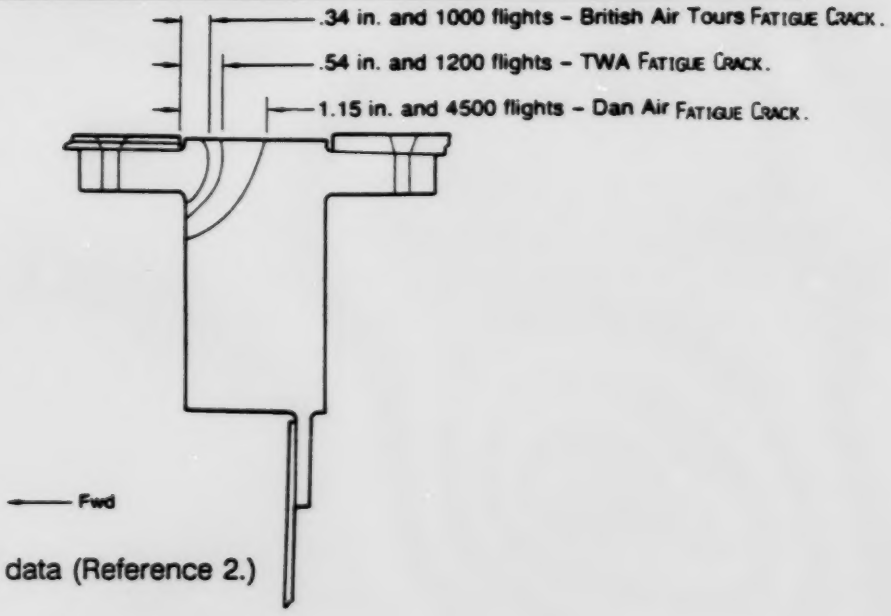
.34 in. and 1000 flights - British Air Tours Fatigue Crack.
.54 in. and 1200 flights - TWA Fatigue Crack.
1.15 in. and 4500 flights - Dan Air Fatigue Crack.
Fwd

Figure 5 - Crack growth data (Reference 2.)

Ground Spoiler Effect on Stabilizer Stresses

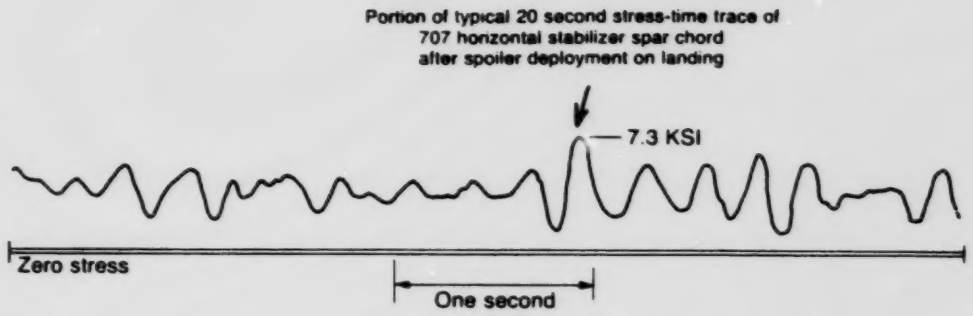
Portion of typical 20 second stress-time trace of
707 horizontal stabilizer spar chord
after spoiler deployment on landing
7.3 KSI
Zero stress
One second

Figure 6 - Ground Spoiler effect on stabilizer stresses (Reference 2.)

Typical Flight Stress Profile

707 Horizontal Stabilizer Spar Chord

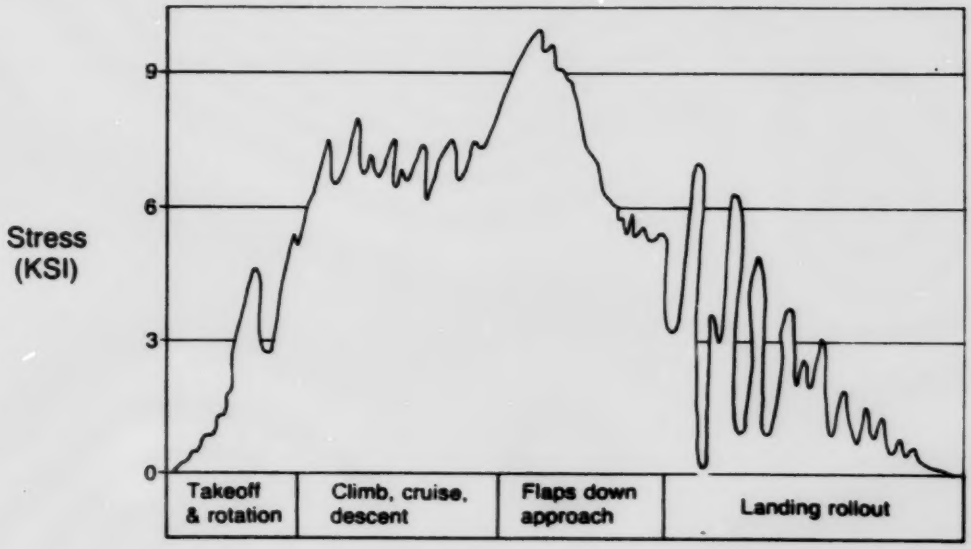

Figure 7 - Typical flight stress profile (Reference 2.)

fatigue. The primary major fatigue crack was found to have propagated rearward across the flange and into the main cross section of the chord.

The investigation revealed that during a normal landing roll, with spoilers deployed and using reverse thrust, the horizontal stabilizers were subjected to oscillating loads at a rate of approximately 5 cycles/sec., which peaked at a value of 80 percent of the maximum load on a typical flight. These oscillating loads, which were found to be caused by speed brake deployment, were not accounted for during the initial fatigue analysis and explain the higher than expected crack growth rate on G-BEBP.

As the result of an earlier American Air Lines B-707-123 accident near Peconic River Airport, Calverton, Long Island, New York, on August 15, 1959, Boeing Airplane Company made a modification on model B-707-138 aircraft that added approximately 1 m (3 feet) to the top of the rudder, added a dorsal fin under the rudder, added boost power to the wider ranges of directional movement, and replaced the original rudder with an improved version, all implemented by means of a service bulletin approved by the FAA.[4]

When the B-707-300/400 series aircraft was developed, the stabilizer assembly was extensively redesigned, but no fatigue tests were carried out on the redesigned stabilizer structure. During the B-707-300 series development flying program, the aircraft was found to have unsatisfactory elevator response characteristics, which were subsequently corrected.

A worldwide post-accident survey of the B-707-300 fleet, following the Dan-Air accident, revealed a total of 38 aircrafts with fatigue cracks present in the stabilizer rear spar top chord similar to G-BEBP. Of this number, four stabilizers required chord replacement.

After the Dan Air accident, the British CAA required Boeing to develop supplemental inspection documents on older aircraft that were nearing their economic design life objective.

2.3 Aloha Accident

This accident occurred on April 28, 1988, when an 18-foot section of a B-737s fuselage ripped off at 7315 m (24,000 feet) as the plane was going from Hilo to Honolulu, Hawaii, with 95 passengers aboard. (See Figures 8 & 9) A flight attendant was swept outside by the explosive decompression. The aircraft made an emergency descent and landed safely at Maui's Kahului Airport.

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[4] See Civil Aeronautics Board Aircraft Accident Report, SA-343, File No. 1-0057, released April 25, 1961.

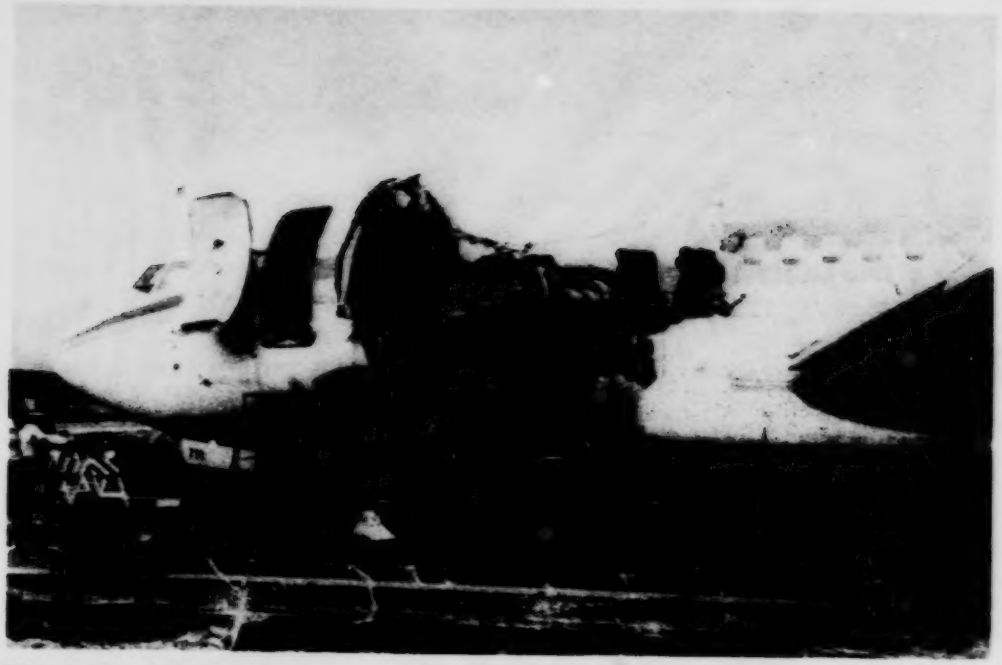

Figure 8 - General View, Left Side of Forward Fuselage (Reference 3.)

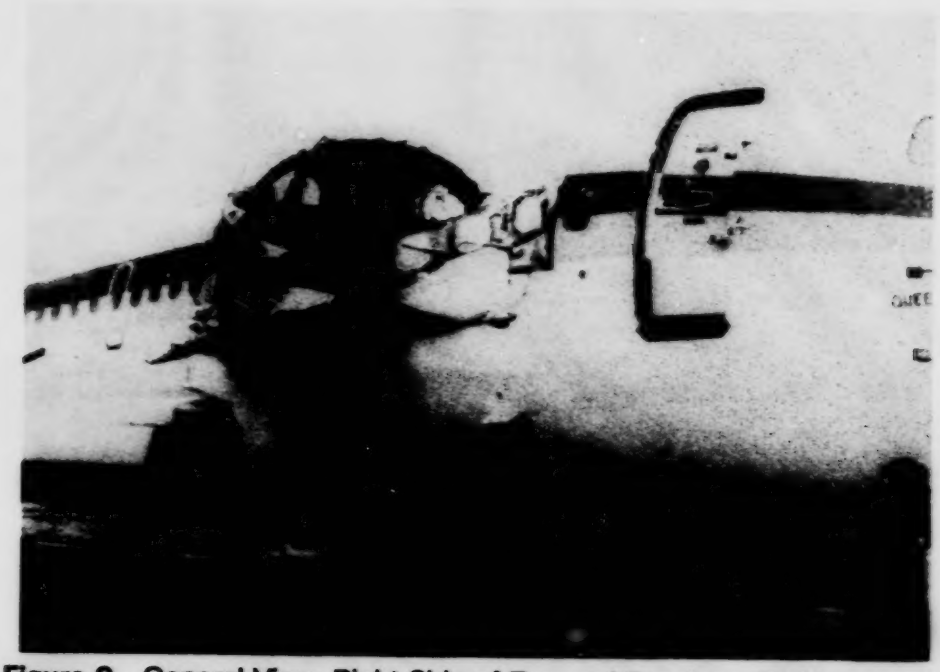

Figure 9 - General View, Right Side of Forward Fuselage (Reference 3.)

Flight 243 involved N-73711, a B-737-297 that was 19 years old. It had 35,496 flight hours and 89,680 flight cycles, the second highest for any B-737.

This fuselage failure was the result of multiple-site fatigue cracking of the skin adjacent to rivet holes along the lap-joint upper rivet row and tear strap disbond, which negated the fail-safe characteristics of the fuselage (See Figure 10). The investigation of this accident concluded that the lap-joint disbonding originated from manufacturing difficulties encountered with surface preparation and/or bond material processing during Boeing's construction of the airplane.[5] The lap joint's disbonding, with resulting corrosion and probable fatigue cracking, was explicitly defined in a Boeing Service Bulletin. However, the serious implications of multiple-site damage were not realized, a permanent solution was not determined, and corrective action was relegated to repetitive visual inspections. There was no consideration given to the joining of adjacent cracks which might develop during extended service other than normal "state of the art" fatigue evaluation. The investigation disclosed that there was sufficient information available to Aloha Airlines to alert it to the cracking problems associated with the deterioration of lap joint bonds, and Aloha should have followed a maintenance program to detect and repair cracking before it reached a critical condition.

After the accident, a passenger stated that as she was boarding the airplane through the jet bridge at Hilo, she observed a longitudinal fuselage crack. The crack was in the upper row of rivets along the S-10L lap joint, about halfway between the cabin door and the edge of the jet bridge hood. She made no mention of the observation to the airline ground personnel or flight crew.

A special FAA inspection of Aloha four months before the accident did not accurately reflect the airworthiness of the airplane's operating fleet, because the team failed to inspect and report the physical condition of those planes.

Approximately four months before the Aloha accident, and even prior to that time, Boeing made several "aging fleet" inspections and surveys of the Aloha Airlines fleet. However, when discussing the findings of these inspections with Aloha personnel, Boeing prevented FAA personnel from attending the meeting, citing corporate concern to preserve the privacy of communication between operators and the manufacturer.[6]

The U.S. NTSB investigation report also indicated that in 1987, the Aloha fleet averaged 15.56 flight cycles and 6.0 flight hours per airplane per day.[7] Mechanical dispatch reliability was an impressive 99.59 percent.

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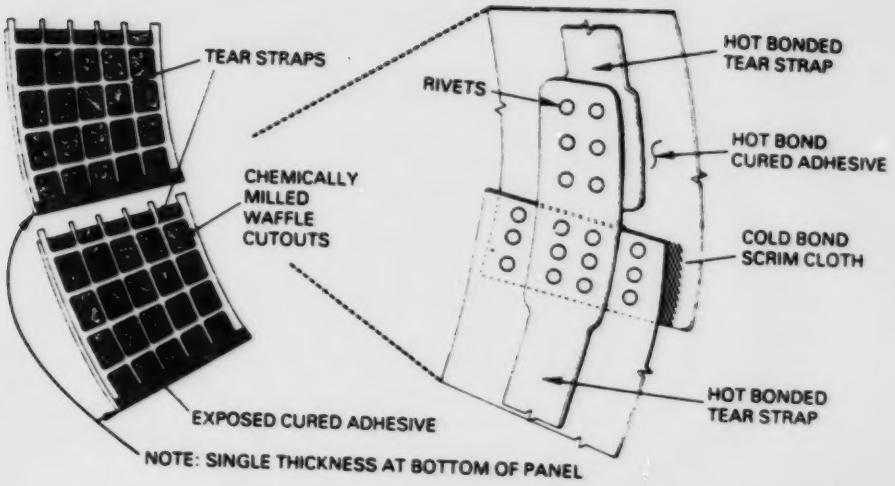
[5] See U.S. NTSB aircraft accident report on Aloha accident.

[6] U.S. NTSB Aircraft Accident Report on Aloha Airlines Accident, P 69.

[7] Ibid, Appendix I, p. 223.

Boeing 737
LINE NUMBER 1 - 291



Boeing 737
LINE NUMBER 292 & AFTER

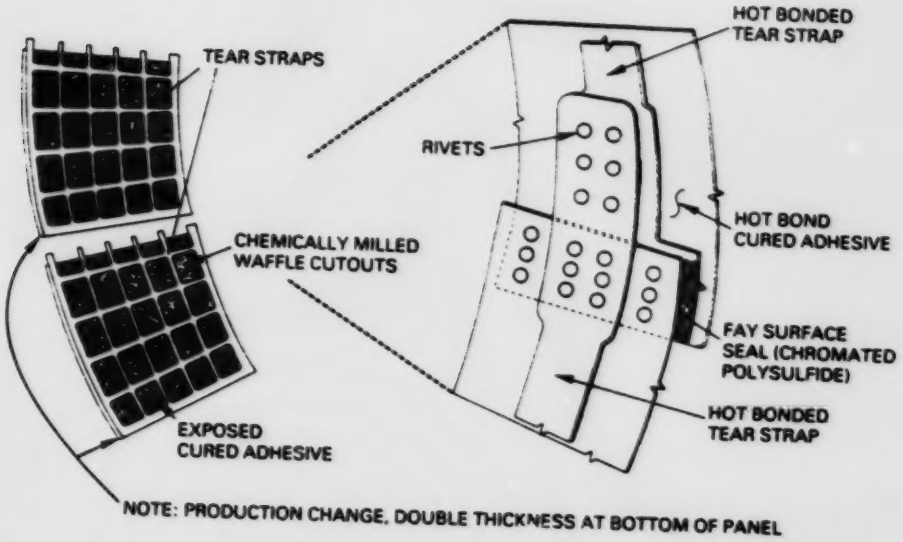

TEAR STRAPS
CHEMICALLY MILLED WAFFLE CUTOUTS
EXPOSED CURED ADHESIVE
NOTE: PRODUCTION CHANGE, DOUBLE THICKNESS AT BOTTOM OF PANEL
RIVETS
HOT BONDED TEAR STRAP
HOT BOND CURED ADHESIVE
FAY SURFACE SEAL (CHROMATED POLYSULFIDE)
HOT BONDED TEAR STRAP

Figure 10 - B-737 Lap Splice configuration, showing cold and hot bonding (Reference 3.)

With respect to maintenance checks, the report indicated that the present Aloha B-737 maintenance check intervals (in flight hours) were as follows:[8]

"A" Check	"B" Check	"C" Check	"D" Check
150 flt. hrs.	750 flt. hrs.	3,000 flt. hrs.	15,000 flt. hrs.

The report further listed a comparison of the "typical" values used for the example program in the B-737 SSID, and the current Aloha B-737 average values as follows:[9]

Repeat Check Intervals in Flight Cycles

Check Level	ALOHA	B-737 SSID	B-737 FLEET
"A"	500	250	160
"B"	2,100	-----	630
"C"	8,100	3,000	2,970
"D"	40,500	24,000	20,500

Table 2. Check Intervals for Aloha Damage Tolerant Rating Checks

Because of the daily frequency of short-duration flights, the rate of accumulation of flight cycles on Aloha Airlines airplanes exceeded the rate of about 1 1/2 cycles per flight hour. Aloha Airlines records indicated that their airplanes accumulated about 3 cycles for each hour of service. The Safety Boards investigation concluded that the 8 years required to complete a "D" check was too lengthy to permit early detection of disbond-related corrosion, to allow damage repair, and to implement corrosion control/prevention with the maximum use of inhibiting agents.[10]

The investigation also noted that FAA's principal inspector for Aloha, although motivated in his surveillance tasks, was overburdened with other responsibilities and was not suitably informed about the age and condition of the airline's fleet nor the nature of its operations. The investigation concluded that the inspector was not specifically trained to deal with lap joint disbonding and corrosion problems, and his efficiency was further eroded by failure to be apprised of information exchanged between Boeing and Aloha

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[8] Ibid, p. 236

[9] Ibid, p. 238.

[10] Ibid, p. 52.

involving aging aircraft.[11]

The lesson learned in the Aloha accident was that the failure of a maintenance program to detect the presence of significant disbonding and fatigue damage ultimately led to failure of a lap joint and separation of the fuselage upper lobe.

The Aloha B-737 involved the 152nd Boeing 737 to roll off the Boeing assembly line. No. 151, which preceded the Aloha airplane, was also involved in a catastrophic accident. On August 22, 1981, 7 years earlier, a B-737 of Far Eastern Air Transport, whose cabin ruptured as it neared the 24,000-ft. altitude near Miao-li, crashed about 96.54 km (60 miles) south of the Taiwanese capital of Taipei while en route from Taipei to Kaohsiung. The cabin fractured in the forward area of section 43, as in the Aloha accident. Witnesses reported total structural failure before the aircraft struck the ground. One hundred and four passengers and 6 crew members received fatal injuries. Both the Aloha and Far Eastern B-737s had been subject to a corrosive saltwater atmosphere involving high humidity during their flights, and they had flown short hops with many landings and pressurizations. The Far Eastern B-737 was 12 years old and had approximately 33,000 takeoff-pressurization-landing cycles. The accident was caused by corrosion-accelerated fatigue of fuselage skin panels.[12] It had aborted its previous flight the day of the accident, losing cabin pressure at 20,000 feet, and the pilot returned for repairs, after descending to 10,000 feet to complete the flight. Investigators determined that the breakup of the fuselage began just as the aircraft climbed through 22,000 feet where the flight and voice recorders ceased operating.

2.4 Air Canada Incident

On September 17, 1979, an Air Canada DC-9-32 departed Logan International Airport, Boston, enroute to Yarmouth, Nova Scotia, with 40 passengers and 5 crew members aboard. About 14 minutes after takeoff, at an altitude of approximately 7620 m (25,000 feet) the tailcone along with the aft cabin pressure access door and a portion of the aft cabin pressure bulkhead separated from the aircraft, resulting in rapid decompression. The aircraft landed safely at Logan approximately 38 minutes after takeoff with only one flight attendant injury from decompression.

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[11] See Figure 10.

[12] Program Plan National Aging Aircraft Research Program, U.S. Dept of Trans., FAA Technical Centre Atlantic City International Airport, New Jersey. Doc # DOT/FAA/CT-88/32, p. 1.

The fracture of the aft pressure bulkhead initiated from a large preexisting crack below the access door area. Radiographic inspection of the bulkhead was accomplished on May 5, 1979, approximately 5 months before, and showed a clearly discernible and easily identifiable fatigue crack. However, company inspection and quality control procedures allowed this discrepancy to go undetected. Air Canada ordered an immediate examination of its fleet of 43 DC-9-32 after the incident. Two of these other DC-9s had cracks in the same area, and despite established inspection and quality control procedures, 33 other DC-9 aircraft belonging to other air carriers were found to have similar cracks of varying lengths in the same area of the aft pressure bulkhead.

What were the lessons learned from this incident? I believe the lesson is that timely and effective inspections and quality control practices are necessary if we are to maintain an airworthy aging fleet.

3. AIRCRAFT DESIGN REQUIREMENTS

3.1 Safe-Life Concept

"Safe-life" is a term applied to structure that has been evaluated to be able to withstand the repeated loads of variable magnitude expected during its service life without detectable cracks. Safe-life structure often has a non-redundant arrangement of load carrying members. Because failures of elements of this type of structure can be critical to the safety of the aircraft, fatigue life limits are carefully determined and it is mandatory to remove safe-life components from service when the life limits are reached.

Safe-life structures refer to components that are not damage tolerant. These are generally single load path-types of structures and often involve the use of extremely high strength materials. If flawed, such details will fail at limit load before the flaw can reasonably be detected by non-destructive means. Therefore, in order to avoid single load path failure and ensure the structural integrity of the aircraft, the structure is periodically replaced. A typical example of safe-life structure is the landing gear.

A service life, either in numbers or cycles of operation or in hours, is established. For this design philosophy to be reliable, the engineer must know the loading conditions throughout the life of the structure and the material response to these loads, and the material must behave in service as it does in any testing program used to establish the material response. If all these conditions are not known, then a fairly large factor of safety must be used to account for the unknown variables.

Accordingly, the life of the component is predicted by the best analytical and experimental techniques available and the component (airplane) is removed from service at or before its predicted life. Thus, the possibility of structural failure is eliminated.

3.2 Fail-Safe Concept

"Fail-safe" is a term applied to structure that has been evaluated to assure that catastrophic failure is not probable after fatigue failure or obvious partial failure of a single, principal structural element.

The fail-safe concept uses redundant or multiple load paths. In this design philosophy, components are loaded in fatigue. Appropriate safeguards are incorporated into the design of a structure so that even if a local failure occurs, the structure is safe; that is, catastrophic failure of the structure does not occur even if a member fails. Thus, the structure can be repaired in an orderly manner, and a failure will leave the product unaffected or will convert it to a state in which no injury or damage will occur.

Examples of fail-safe design include multiple load-path members or structural redundancy;

use of crack arresters in the aircraft industry; and inspection intervals for all fatigue-loaded members.

3.3 Damage-Tolerant Concept

"Damage-tolerant" is a term applied to structure that has been evaluated to ensure that should serious fatigue, corrosion or accidental damage occur within the operational life of the aircraft, the remaining structure can withstand reasonable loads without failure or excessive structural deformation until the damage is detected. Characteristics often, but not always, found in damage-tolerant structure include multiple load paths, materials with slow crack growth rates, ability to withstand relatively long cracks before unstable crack growth occurs, and design for good inspectability. An effective structural inspection program is an essential element of damage-tolerant design and must be developed to permit adequate opportunity to detect damage in principal structural elements before such damage becomes critical.

A principle that has evolved from the early fail-safe principle is that of damage-tolerant design. In the mid-1970s, newly certificated aircraft were required to be certificated or designed under the damage-tolerant concepts. This concept stipulates that a component must be tolerant of damage and still be able to carry the extreme loads resulting from the damage. The design is such that following failure, the airplane can still continue to fly safely until the condition is discovered and corrected, and includes tolerance to corrosion, accidental damage, and fatigue.

All large transport category airplanes today are designed to be damage tolerant. There is no limit to the service life of damage tolerant designed aircraft provided inspections are carried out and timely repairs or replacements made for airplanes exceeding the economic design life objectives.

The Airworthiness Manual, Chapter 525.571 for transport category airplanes, states that the damage-tolerance evaluation of an airplane "... must include a determination of the probable locations and modes of damage due to fatigue, corrosion, and accidental damage. The determination must be by analysis supported by test evidence and (if available) service experience."

4. AIRCRAFT AGING DEFINED

4.1 Fatigue

The fatigue strength of any airframe must consider the repetition of the cyclic loads accumulated during the service life of that airframe. This can be illustrated by the relationship of cyclic stress and cycles of stress observed in Figure 11, which come together to produce failure.

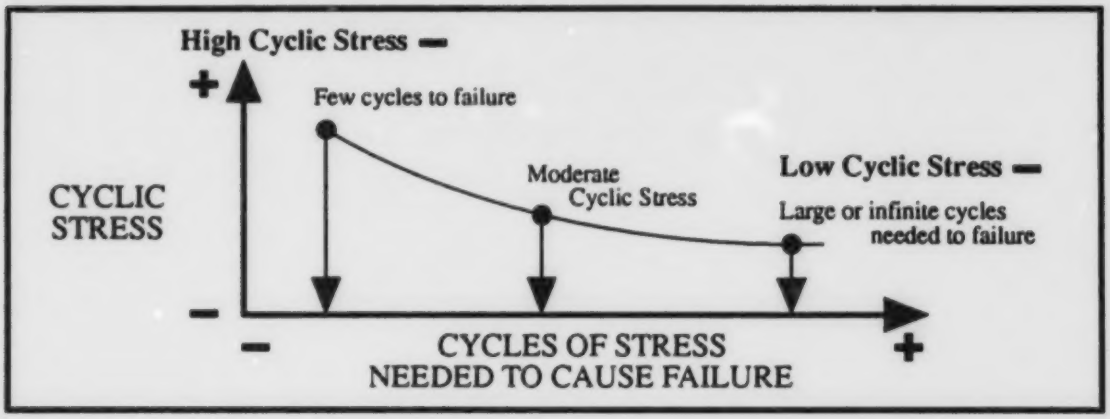

Figure 11 - Relationship of cyclic stress to cycles of stress

A high cyclic stress requires fewer cycles to produce failure. Moderate levels of stress require a larger number of cycles to produce failure, and a very low cyclic stress may require an infinite number of cycles to result in failure.

4.2 Crack growth

Cracks in pressure chambers usually start near rivet holes or on skin due to stress and bending as a result of pressurization cycles. Rivets usually do not "swell" in the hole sufficiently to aid crack growth.

Because of the round shape of fuselages and the bending effects due to shell curvature, stress cracking usually begins around rivet holes and then propagates from rivet hole to rivet hole. This propagation can finally result in a 43- to 60 cm (18- to 24-inches) crack from rivet to rivet or a crack that follows the weakest failure path. To prevent crack growth, the amount of high gross stress, the material fracture toughness, and the geometric design detail must be considered. Also, whether the crack is longitudinal or circumferential, and whether there are failed longerons and stringers beneath the cracked skin have a bearing on the type of failure experienced.

4.3 Disbonding

The first adhesives for bonding structural or load-bearing assemblies occurred in aircraft during WWII. In the ensuing years, extensive research was conducted in the aircraft industry to develop, evaluate, and use adhesives for bonding aluminum, stainless steel, titanium, and other materials. High-temperature adhesives were developed in space applications in the mid to late 1960s. As a result, many cold and hot bonding adhesives are now available for use in constructing aircraft.

The skins of the early Boeing aircraft were joined by means of a cold-bonding process. Rivets fastened the skins and lap splices together, but if the bonding loosened, as it did in many of the first 291 B-737 aircraft built, the rivets became the lone fastener and were subject to stress during cabin pressurization. Boeing's cold-bonding process used an epoxy impregnated woven "scrim" cloth to join panels together. Production process difficulties and moisture contributed to disbonding of these joints. After 1972 and airplane number 292, a redesigned smooth, close fitting "fay" surface-sealed lap joint with increased joint thickness was introduced (See Figure 10).

During B-737 service, moisture entered the joint in areas of disbonding and corrosion occurred. This contributed to further disbonding of the joint because of the accumulation of oxides, water wicking in the joints, and the freeze-thaw cycles.

4.4 Corrosion

Normally, the signs of aging in a piece of equipment are wear and tear, and fatigue. Corrosion, however, is a very different aging problem. Corrosion is the process of eating or wearing away gradually, as if by gnawing, especially by chemical action, or the chemical deterioration of a metal. It has been stated that corrosion accelerates crack growth by about fivefold. (See Figure 12).

Aircraft structures begin to deteriorate from the time they leave the manufacturer's plant. This occurs in the form of mechanical damage such as abrasions, galling, and wear or fatigue. Deterioration will also occur by corrosion, which varies between operators and within an operator's fleet. Airplanes that have been subject to a corrosion-prevention program from entry into service are often corrosion free.

Corrosion damage increases with time, and as an aircraft becomes older the effects of corrosion become more severe. If not detected and repaired, it can become a serious hazard to the structural integrity of the aircraft. Corrosion, therefore, can be cumulative and has a marked effect in reducing the life of an aircraft, particularly with aircraft intended to remain in service for long periods of time. Figure 13 shows this schematically. Here, corrosion damage is superimposed on fatigue damage of short-life and long-life aircraft, illustrating how corrosion can be responsible for major reduction in life.(See Figures 14 and 15).

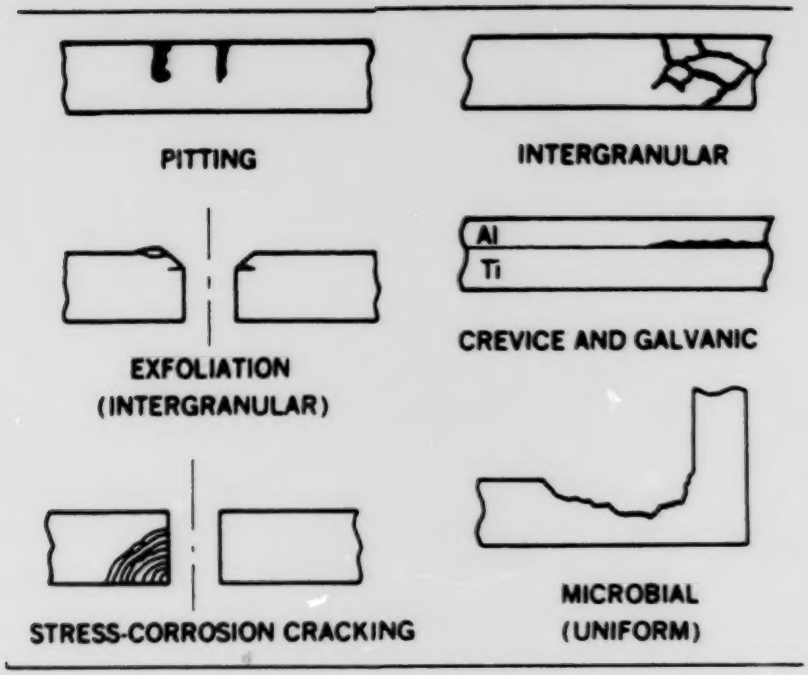

Figure 12 - Types of Corrosion (Reference 4.)

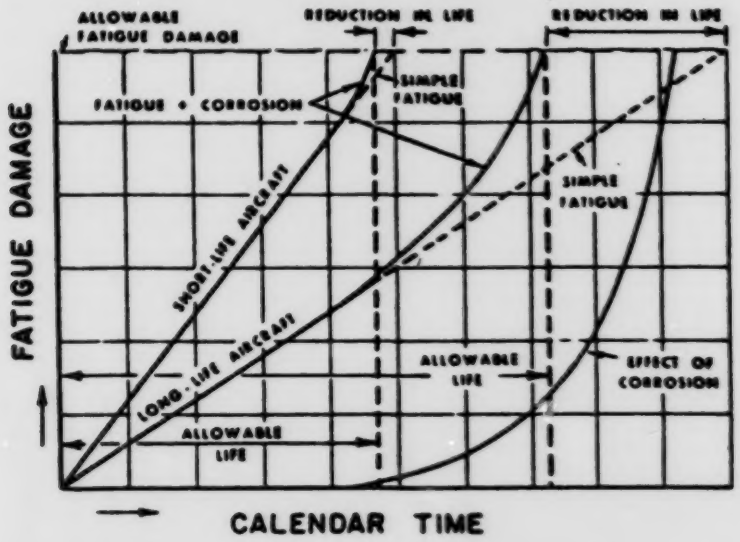

Figure 13 - The Effect of Corrosion on the Fatigue Lives of Long and Short-life Aircraft (Reference 5.)

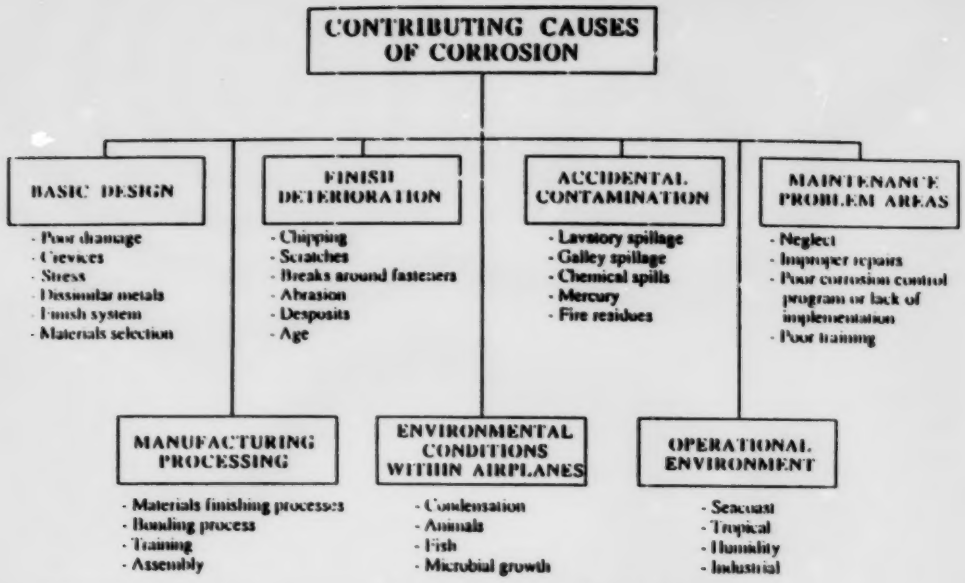

Figure 14 - Contributing causes of corrosion (Reference 4.)

1 UNDER DE-ICER BOOTS
Moisture may collect under the boots and result in corrosion.
2 FLOOR SUPPORTS AND FLOORING
Metal floors and substructure will corrode if continually in contact with moisture of any kind.
3 PASSENGER, CARGO, AND CREW DOORS
Floors and structure in these areas corrode as a result of exposure to rain water and condensate.
4 GALLEY AREAS
Spilled food, fruit juices, and other liquids in prolonged contact with metal structure will cause corrosion, particulary when protective coatings are allowed to deteriorate.
5 AREAS IN PATH OF EXHAUST GASES
Exhaust gases on the nacelle and wing skins and seeping into the wing structure may permeate the protective finish and cause corrosion underneath.
6 INTEGRAL FUEL TANKS
Corrosion may occur at low points inside the integral fuel tanks where water condensate gathers. Integrally stiffened panels do not have aluminium cladding and are more prone to corrode.
7 LAVATORY AREAS
Soapy water and human wastes in these areas promote rapid corrosion and deterioration of structure.
8 BATTERY AREAS
Spilled battery electrolytes are extremely corrosive.
1
2
3
4
5
6
7
8

Figure 15 - Most susceptible areas of corrosion (Reference 5.)

In Transport Canada's evaluation of aging aircraft, discussed in Appendices B and D, most operators stated that they had a corrosion control program. However, TC specialists found that these programs were nothing more than corrosion work cards within the maintenance program. In some instances, the programs did not reflect the operating environment of the aircraft. TC has recommended improvements in this area.

4.5 Multiple Site Damage (MSD)

If we design pressurized cabins to sustain extremely large damage by maintaining reasonable stress levels, choose materials with high fracture toughness, and present a good crack-arresting design, we can protect an airplane from single-site inadvertent damage, accidentally induced. Where multiple-site damage occurs - a condition where small cracks, some invisible, appear and propagate at both sides of each hole in a row of rivets or fasteners - catastrophic failure may occur prior to discovery of these small cracks.

Two recent accidents--the Far Eastern Air B-737 near Taiwan, Formosa in 1981, and the Aloha B-737 in 1988 near Maui, Hawaii, involved multiple-site damage. These accidents show that MSD must be detected early at very small crack lengths and in time if MSD is to be found and repaired before linkup and fracture occurs.

MSD could very well invalidate the original fail-safe design features of the current pressurized aging fleet. To ensure that MSD will never occur during the operational life of an airplane, full-scale fatigue testing of representative sections of pressurized cabins is performed for a minimum of two service lifetimes and followed by tear-down inspection.

There are considerable differences in manufacturer's approaches to MSD in their aircraft. Boeing believes that the potential for MSD is already accounted for in their inspection program and a lead crack will always precede a condition where the structure will fail from net section yielding. McDonnell-Douglas believes that they design and test to ensure that MSD will not occur in the operational life time of aircraft. Lockheed designs their aircraft so that detectable cracks precede the occurrence of MSD.

5. STRUCTURAL EVALUATION

5.1 Structural Safety Factors

This addresses an attempt to establish realistic inspection intervals by using simulation to delve into multiple-site damage. The attempt is to predict the probability of a crack size with limit load or less; the distribution for the crack size during inspection; the probability of detecting the crack immediately; and the cumulative probability of detecting the crack. This would all be done to ensure continued safe operation of the aging airplane fleet and would entail hands-on simulation techniques for establishing realistic inspection intervals.

AIRFRAME LOADS
o LANDING AND GROUND LOADS
o TAKEOFF LOADS
o GUST LOADS
o MANEUVERING LOADS
o THRUST LOADS
o PRESSURIZATION LOADS

Figure 16 - Airframe loads

5.1.1 Fatigue Analysis/Test

Chapter 525.571 of Transport Canada airworthiness standards for transport category aeroplanes describes the mandatory fatigue evaluation of structures, the prescribed load tolerances, and the kinds of structural damage that must be able to be withstood in flight.

Certain compliance by Boeing deHavilland and Canadair has been accomplished as follows: concerning the DHC-7, it has been type approved to the pre-amendment 45 fail-safe requirements. Components fatigue tested include the full structural airframe, landing gear, nacelle forward fuselage, and various sub-components. The full airframe was tested to two lifetimes or 80,000 flights (cycles), one lifetime being defined as 40,000 flights. The DHC-7 has an ongoing, active maintenance review program with participants from virtually all operators. There is also an aging aircraft program on the DHC-7 and a recently completed airworthiness directive/service bulletin review. A corrosion control manual is to be completed shortly.

Both the Canadair CL-600/601 and the DHC-8 have been type approved to the post-amendment 45 damage tolerance requirements using the following design principles:

> "All Principal Structural Elements (PSEs) are designed using fracture mechanics principals exclusively. S/N (Miner's Rule) fatigue is not used for damage tolerance compliance. The airframe is considered to have typical imperfection flaws consistent with MIL-83444 at time of manufacture (i.e., The structure is considered cracked when new - 0 hours on airframe)."

All PSEs are inspected by 1/2 design lifetime, and have inspection requirements in place at type approval. NDT inspections were developed for all PSEs at time of the approval.

The Boeing deHavilland DHC-8 has had the following components fatigue tested: the full structural airframe, the forward fuselage, the nacelle, landing gear, and various sub-components. The DHC-8 airframe was tested to 160,000 flights (cycles) with one lifetime being 80,000 flights (cycles). The forward fuselage section was tested to 216,000 flights. The nacelle has been tested to over 200,000 cycles and continuing.The Canadair CL-600-601 has had the following components fatigue tested: the full structural airframe, the forward fuselage, the flight-control surfaces,the landing gear, engine mounts, and various sub-components. This aircraft was tested to 60,000 hours with one lifetime being 30,000 hours. The first lifetime was a durability test while the second was for damage tolerance.

5.1.2 Proof Pressure Test

This method to substantiate the structural integrity of in-service aging airframes uses periodic proof testing to ascertain whether the structural integrity of older airplane fuselages will withstand repeated loadings. Aircraft cabin structures are usually designed for less than 100,000 pressurization cycles; and almost every aircraft cabin structure has been proof loaded to at least 1.33 P. Accordingly, it would not be dangerous to repeat that condition somewhere in the airplane's life if the structure has seen, already, that amount of loading.

Proof pressure testing can provide a simple, rapid, and effective demonstration of structural integrity. It has proven successful for military airframes such as the F-111 wing box and the B-52 wings. It can be considered as a non-destructive inspection method. Solid rocket motor cases are proof tested as part of the acceptance procedure.

Chapter 525.365 of the airworthiness standards for transport category airplanes specifies the pressure cabin loads that must apply:

> "(d) The airplane structure must be strong enough to withstand the pressure differential loads corresponding to the maximum relief-valve setting multiplied by a factor of 1.33, omitting other loads."

5.2 Structural Surveillance

Commercial aircraft maneuver and gust-load environment can be better assessed by new technology that measures the stress of fuselage pressurization loads, gust effects on fuselage loads, and external loading on wings and empennage while in flight and while on the ground by means of strain gauges. This can be accomplished as it was in the NASA flight loads data collection program for the L-1011, the B-727, B-747, and the DC-10 aircraft.

5.3 Structural Life Management

It is generally agreed that the safe lifetime of an aircraft is and should remain an economic determination as long as SIDs are implemented as an adequate means of continuing the safe use of aircraft. However, to assure an adequate "cradle-to-grave" concept, a variety of engineering tasks are required, including design criteria, analyses, tests, development of a material and manufacturing process, quality control requirements, flight tests and load tests, maintenance management and structural life management.

Such a system would create a total life management plan for each aircraft that would monitor every phase, including initial design, in the aircraft's lifetime, to assure a prolonged, safe structural life.

Military forces in both the United States and Canada presently have somewhat similar plans for their aircraft. These usually permit service life extensions, offer structural integrity, and provide a journal of good maintenance records on each aircraft.

6. MAINTENANCE - REPAIR - INSPECTION

Several problems in the maintenance/repair/inspection areas should be addressed in dealing with the aircraft-aging problem. This is one of the most important areas in evaluating the effectiveness of an aging fleet. Some have said there is no aircraft aging problem but simply an aircraft maintenance problem. The few tragedies, some involving older aircraft in recent years, have been attributed to inadequate maintenance and inspection oversight. For example, as mentioned earlier, the Aloha Airlines accident was caused by the airline's failure to detect fuselage skin and structural defects --Maintenance; by FAA's failure to require certain inspections proposed by Boeing--Inspection; and by lack of action by FAA or the manufacturer to correct structural problems that were discovered as far back as 1981--Repair.

Current maintenance programs do not recognize the significance of airplane age. But although the key elements in an adequately managed air carrier fleet are maintenance oriented, industry maintenance practices and regulatory supervision do not necessarily ensure the integrity of aging fleets. As the Transport Canada Supplemental Inspection Document team disclosed in their report dealing with NDT capability, the larger air carriers have in-house NDT groups staffed with CGSB-certified NDT personnel having an aircraft background.[13] Thus, they have no problem with the NDT requirements. Other smaller operators do not even have NDT capability and have integrated the SID inspections into the "C" and "D" checks performed outside their organization or outside Canada, relying on foreign maintenance facilities to provide competent NDT personnel. The United States has no national NDT standards for personnel certification, and maintenance standards vary widely in the United States. Further, a portion of the Canadian fleet is operated and maintained by approved contract maintenance agencies outside the country, where Transport Canada may or may not have official cognizance or jurisdiction. In some instances, these aircraft may not return to Canada for long periods.

Thus, maintenance varies among air carriers, and varies between airplane and airplane within a carrier. Complicating this issue is the widespread practice among banks, trust companies and equipment leasing companies to buy new and used aircraft and lease them back to various operators, foreign and domestic.

As of 1990, 51 percent of the U.S. 4,125-aircraft fleet, or 2,100 aircraft, are leased. Fifty percent of the Canadian 3,387-aircraft fleet or 1,697 aircraft are leased. What bearing does this have on aging aircraft? Aircraft lease operators, while not necessarily operating their aircraft unsafely, do not have as much economic incentive to perform the kind of high quality and costly maintenance that would extend the aircraft's life as might operators who own their airplanes. Many of the aircraft in Canada are leased for long terms of five

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[13] See Appendix "C"

or more years. Under such circumstances, there is an incentive to provide quality maintenance while the aircraft is under the lessee's control. Attempts to obtain information on leased aircraft in Canada from Statistics Canada and the Aviation Statistics Centre were not successful.[14]

6.1 Canadian Air Carrier Maintenance Costs

Although comparisons can be hazardous, it is interesting to compare Canadian and U.S. air carrier operating expenses and maintenance costs. Tables 3 and 4 are comparisons of total operating expenses and total direct maintenance costs and percentages for U.S. and Canada. Although the air carriers in both countries have shown a comparable growth rate in total operating expenses, the U.S. air carriers have shown a 72 percent growth rate in direct maintenance costs over 5 years, compared with Canada's 26 percent growth rate. The percentage of maintenance costs in Canada has remained rather steady over the past 5 years, while U.S. maintenance costs have increased steadily, although totals of each chart indicate rather consistent maintenance percentages among carriers of both countries.

The reasons for these differences could be the relative size differences of the two fleets, the fact that Canadian air carriers have been steadily replacing older aircraft, and, possibly, that Canadian air carriers have used better maintenance techniques.

YEAR	TOTAL AIRCRAFT OPERATING EXPENSES	TOTAL DIRECT MAINTENANCE COST	DIRECT MAINTENANCE PERCENTAGES
1984	20,360	3,316	16.3
1985	20,934	3,677	17.6
1986	20,065	4,500	22.4
1987	22,037	4,975	22.6
1988	23,815	5,704	24.0
TOTAL	107,211	22,172	Avg. 20.7
5 Year Growth Rate	17% Growth Rate	72% Growth Rate	

Table 3 - Comparison of operating expenses and maintenance costs - United States air carriers (U.S. dollars in millions).

[14] See Appendix H for leasing information concerning aircraft in the United States.

YEAR	TOTAL AIRCRAFT OPERATING EXPENSES	TOTAL DIRECT MAINTENANCE COST	DIRECT MAINTENANCE PERCENTAGES
1984	3,241	561	17.3
1985	3,636	661	17.3
1986	3,726	678	18.1
1987	3,790	767	20.2
1988	3,770	704	18.7
TOTAL	18,165	3,336	Avg. 18.4
5 Year Growth Rate	16.3%	26%	

Average Exchange Rates: $1.15 Canadian
$0.85 U.S.

Table 4 - Comparison of operating expenses and maintenance costs - Canadian Level I & II air carriers (Canadian dollars in millions).

6.2 In-House vs Outside Maintenance for Air Carriers

U.S. efforts to make aging aircraft safer have resulted in a lack of repair capacity, and stepped-up maintenance over the next few years could conceivably strain the industry's demand for outside maintenance, that is, contracted maintenance conducted outside the air carrier's facilities. The reasons for increases in demand for maintenance have been (1) the need to modify and repair aging aircraft; (2) the increased growth of air carrier fleets; and (3) the increases in air travel since deregulation in 1978.

Outside maintenance costs in both countries have shown a steady rise in the 5-year period. According to Tables 5 and 6, U.S. total direct maintenance expense shows a 72 percent growth rate. A 25.5 percent growth rate in Canada compares with a 72 percent rate among U.S. air carriers for total direct maintenance costs. But although Canadian outside maintenance costs show a 52 percent growth rate, U.S. costs for maintenance accomplished outside air carrier facilities have increased 185 percent.

Canada could help fill this U.S. void, but not every repair station in Canada is capable of performing heavy airframe maintenance. Constraints include lack of hangar space, shortage of skilled aircraft mechanics in some markets, and inability to tool-up in spare parts, as well as problems with administrative requirements and the installation of new facilities.

YEAR	MAINTENANCE	OUTSIDE REPAIR	OUTSIDE PERCENTAGE
1984	3,316	423	12.8
1985	3,677	578	15.7
1986	4,500	720	16.0
1987	4,975	861	17.3
1988	5,704	1,208	21.3
TOTAL	**22,173**	**3,790**	
5 Year Growth Rate	72%	185.5%	

Table 5 - Comparison of outside maintenance work to total direct maintenance, United States air carrier (U.S. dollars in millions).

TOTAL (All Carrier)				LEVEL I CARRIER			LEVEL II CARRIERS		
Year	Total	Outside	Percent Outside	Total	Outside	Percent Outside	Total	Outside	Percent Outside
1984	561	65	11.6	419	43	10.5	26	8	30.0
1985	628	78	12.6	458	55	12.1	45	8	17.8
1986	674	102	15.1	475	67	14.2	63	12	20.0
1987	767	91	11.9	522	45	8.7	78	19	24.6
1988	704	99	14.1	562	70	12.6	142	28	20.2
TOTAL	**3,336**	**436**		**2,438**	**283**		**356**	**76**	
5 Year Growth Rate	25.5%	52.1%		34.2%	61.1%		428.6%	255.5%	

Table 6 - Comparison of outside maintenance to total direct maintenance, total Canadian air carriers, and Level I and Level II carriers.

6.3 Maintenance Cost Analysis

New technology, inspection techniques, and construction techniques are developed in an attempt to reduce the direct cost of maintenance of aircraft. However, data from aviation operating statistical centres in both the United States and Canada over recent years indicate that maintenance costs are steadily rising, but that the maintenance share of total expenses has remained relatively steady (See Tables 7 and 8).

Year	Maintenance Expenses	Total Operating Expense	Maintenance Share of Total	Fuel Expenses	Total Operation Expense Less Fuel	Maintenance Share of Total Less Fuel
1984	3,933.9	41,673.5	9.4	9,361.7	32,311.8	12.8
1985	4,491.9	45,236.2	9.9	9,326.7	35,911.5	12.5
1986	5,528.6	49,201.8	11.2	6,939.1	42,262.7	13.1
1987	6,153.6	54,561.1	11.3	7,485.9	47,075.2	13.1
1988	7,251.7	61,114.7	11.9	7,454.2	53,660.5	13.5
5 Year Growth Rate	84.0%	46.7%		25.6% Decrease	66.0%	

Table 7 - United States scheduled airlines maintenance cost analysis (U.S. dollars in millions).

Year	Maintenance Expenses	Total Operating Expenses	Maintenance Share of Total	Fuel Expenses	Total Operation Expenses Less Fuel	Maintenance Share of Total Less Fuel
1984	7,047	32,410	17.3	11,165	21,244	26.4
1985	6,281	36,368	17.3	12,232	24,136	26.0
1986	6,749	37,269	18.1	11,242	26,027	26.0
1987	7,674	37,900	20.2	10,829	27,071	28.3
1988	7,047	37,708	18.7	10,870	26,838	26.3
5 Year Growth Rate	Variable	16.3%		2.6% Decrease	26.3%	

Average Exchange Rates: $1.15 Canadian
$0.85 U.S.

Table 8 - Canadian scheduled air carriers maintenance cost analysis (Canadian dollars in millions).

6.4 Inspection

One of the key areas where improvements could be made in the maintenance of aging aircraft is aviation safety field inspector staffing.

During the field visits made to various aircraft manufacturers and companies using older aircraft (See Appendix F), it was revealed that very few Transport Canada airworthiness inspectors have a good basic background in structural airworthiness. Several inspectors with 18 and 20 years of maintenance experience indicated they had never had any practice, training, or background in dealing with lap joints, multiple-site damage, or disbonding. During the aircraft-aging project, a review was made of the airworthiness inspector staffing within Transport Canada.

Transport Canada's Aircraft Maintenance Engineer licensing system lists certain ratings indicating the types of aircraft or other aeronautical products to which the license privileges apply. Category "S" - Structures - is a specialised maintenance rating. Under structures, group S-31 is concerned with wooden structures. S-32 is concerned with tubular structures, and S-33 is concerned with sheet metal structures. Satisfying acceptable experience for a structures rating involves sheet metal, fibre, wood, and fabric repair and some treatment of corrosion and protective treatment. These general descriptions leave much to be desired concerning an inspector who must deal with supplemental inspections, advances in fuselage pressurization technology, fatigue-crack propagation, lap joint repair, corrosion detection and repair, and other aging-aircraft maintenance.

Further, there is a critical shortage of category "S" structural maintenance engineers in Transport Canada as well as a critical shortage of airworthiness inspectors.

7. HUMAN FACTORS

The human factors aspects of aircraft aging involve a review of airframe inspection training and work practices used by the military and by industry. The topics are many but all focus on human performance in maintenance and inspection.

Task analysis examines the activities considered crucial in maintaining older aircraft. Observation and study of subtasks under the larger principles or maintenance tasks, with a view to developing training, communication, and environmental improvements, are stressed.

Training design draws on the successful experience gained from similar fields to present inspection errors by means of research strategies and computers.

Equipment design would address, for example, non destructive inspection technology and aviation maintenance tools, recognizing human frailties and the limitations of such error-prone inspections. Environmental design addresses the job stress and low human productivity rates that might be associated with poor environmental factors, such as access, lighting, noise, and temperature, and how these can be better controlled.

Job performance aids include the many NASA and military computer-based systems that provide on-line visual and audio instructions on maintenance and inspection. Thus, enlarged, schematic views of aircraft substructure and parts description can be made available for application to the airplane inspection process.

Selection/placement/motivation involves the study of relationships between personnel characteristics, job performance, and job stress to identify variables that could improve maintenance and inspection.

All these elements could be incorporated into a human factors handbook for use by maintenance and inspection technicians and managers. Such a handbook would assist managers in dealing with human performance. The U.S. FAA is presently developing such a handbook.

8. DETECTION/PREDICTION OF AIRCRAFT AGING

What can be done to predict the greying of the aircraft fleet, or to measure the flight loads or other phenomena that cause aircraft aging? Since the increase in inspection tasks brought about by rapid expansion of the aging fleets, there has been much new emerging technology related to aircraft aging. Some of these were adapted from earlier technology to detect flaws and others are efforts to improve and meet the inspection challenge of the aging aircraft fleet.

Fibre Optic sensors are being studied at the University of Toronto Aerospace Studies. Research in acoustic-ultrasonics is under way at the Institute of Aerospace Research in Ottawa. More composite materials are being used in aircraft structure, as evidenced by the Beech "Starship".

The U.S. Air Force uses automated NDT on some of its high-performance aircraft (F-111 and A-10). At a base near Sacramento, California, the Air Force Logistics Command deploys a giant automated neutron radiography machine to hunt down corrosion on F-111 fighter-bombers. By bombarding the 73-feet-long aircraft with neutron radiation, the machine can detect traces of water as well as molecules that could corrode metal. The N-Ray machine does in 16 hours what human inspectors would take a month to do. The cost of this device is $14 million.

Flight loads data collection is one of the long-term aging aircraft efforts. This can be accomplished by the use of a subject-smart recorder or computer. A "smart" recorder is an on-board microprocessor-based system that can analyze data and decide what should be stored for post-flight evaluation. Some of the aircraft usage data that a "smart" computer can provide are: typical flight profile statistics, such as frequency distributions, tables of flight duration, control surface usages, air speed, altitude, acceleration statistics for calculating and measuring the maneuver loads and deriving the gust velocities, and takeoff and landing parameters for distance and velocity information.

8.1 Service Difficulty Reporting System

The Service Difficulty Reporting System (SDR) is an international comprehensive arrangement for the collection, organization, and dissemination of information on specific problems occurring in aircraft systems and components. The purpose of this system is to provide information to aircraft regulators, manufacturers, and carriers, so that they can analyze the data, spot trends, and take appropriate corrective action.

Reports are obtained from all segments of the aviation industry on failures, malfunctions, and defects in aeronautical products that could adversely affect flight safety. The SDRs are usually coded and filed at some central location or in a computer, for statistical and analytical purposes.

Because aviation regulation agencies in both the U.S. and Canada have limited inspection resources, such reports must be used not only to allocate resources for aircraft inspections, pilot inspections, and repair-station inspections, but also to develop airworthiness directives, and to identify trends and specific aircraft problems.[15]

Chapter 591 of the Airworthiness Manual establishes the requirements and procedures for presenting service difficulty reports to the Minister of Transport in Canada. These reports are now mandatory for all Canadian air carriers, but the reports have not been received in great volume. For example, during the last ten years the following number of SDR reports have been received by Transport Canada on the following aging aircraft:

B-727	7 reports	deHav. DHC-6	30 reports
B-737	14 reports	deHav. DHC-7	3 reports
B-747	3 reports	Fokker F-27	1 report
DC-8	9 reports	Airbus 300	0 reports
DC-9	17 reports	Airbus 310	2 reports
DC-10	1 report	Convair 580	62 reports
L-1011	1 report	HS-748	4 reports

As evidence that better use of SDRs would be productive, one need only consider how these reports could have been used to determine trouble spots prior to the occurrence of several catastrophic aircraft accidents. For example, on May 25, 1979, an American Airlines DC-10 aircraft, N-110AA, during takeoff from Chicago's O'Hare International Airport enroute to the Los Angeles International Airport with 258 passengers and 13 crew members, crashed on takeoff, approximately 800 m (1/2 mile) beyond the end of the runway 32-right. The left engine and pylon had separated from the aircraft during takeoff as a result of fatigue failure of the pylon attach structure. Subsequent review of SDRs indicated evidence as far back as 1974 that air carriers were reporting problems with cracks and embrittlement of pylon attach structures and bolts on DC-10 aircraft.

The investigation of the Aloha Airlines, B-737-200, N-73711 accident near Maui, Hawaii, which occurred on April 28, 1988, indicated considerable data from the FAA SDR base pertaining to the B-737 fuselage. From the beginning of the current data base (January 1983) until the date of the accident, 1,352 records were found. Of these, 198 were reports of fuselage skin cracks, and 10 were of cracking at or near lap joints where fatigue cracking developed. Six of the 10 reports involved lap joints in the upper lobe, while the

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[15] This is the essence of a study made by the U.S. General Accounting Office, 1989- "Aging Aircraft: FAA Needs Comprehensive Plan to Coordinate Government and Industry Actions," GAO/RCED-90-75 Aging Aircraft, which urged the FAA to analyze trend data on aircraft maintenance and repair so that FAA inspection resources could be better allocated.

remaining 4 noted cracks from the lower lobe of the fuselage. These were summarized in Appendix H of the Aloha accident report. All of the aircraft cited in the 10 reports were among the first 291 assembled by Boeing.

Table 9 provides a comparison of annual totals of SDR reports received by the Federal Aviation Administration in the U.S. and by Transport Canada in Canada. In the U.S., SDR reports have shown a 64 percent growth rate from 1980 through 1990. In Canada, the SDRs have shown an 850 percent growth rate, due in part to the mandatory requirements established in 1989.

8.2 Corrosion Detection

When it is impossible to monitor or detect corrosion by direct visual examination, special techniques of non-destructive inspection are available. Liquid penetrant inspection (LPI) is a physical/chemical NDI method for surface exposure of cracks, laps, seams, and other surface defects. This method can be applied rapidly, economically and with a high degree of reliability.

In magnetic-particle inspection (MPI), a magnetic field is induced in the component. Cavities interfere with the field and this discontinuity is revealed by a pattern produced by magnetic particles attracted to the surface. This type of inspection is severely limited in aircraft application because magnetized components must be demagnetized and magnetic particles must be removed.

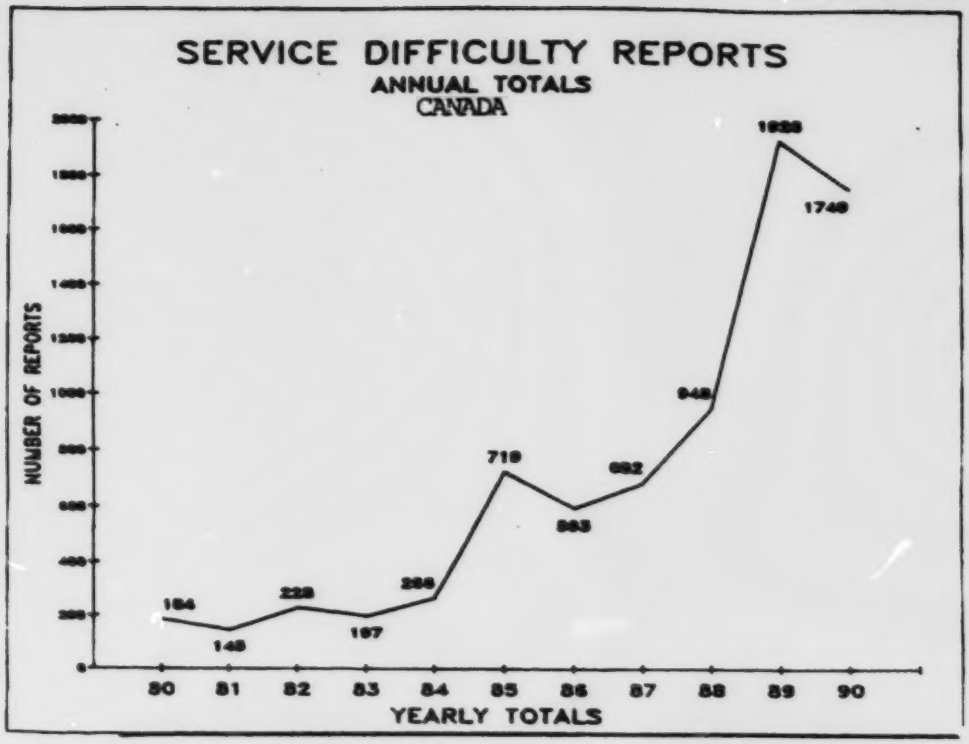
Radiography bathes the component in radiation and variations in thickness and composition are recorded on film, which is then examined. This NDT method detects corrosion in areas of aircraft such as the internal surfaces of skins, stringers, and mating surfaces of riveted structures.

Ultrasonic inspection induces high frequency sound waves into the material to detect surface and subsurface flaws. This method is useful for detecting crack-like discontinuities such as stress corrosion cracks, intergranular corrosion cracks, corrosion fatigue cracks or deep pits.

In eddy current inspection, a coil carrying electrical current is brought into close proximity with the part to be tested. This field is affected by the presence of cracks. Eddy current inspection is used for detecting fatigue, stress corrosion, and intergranular corrosion cracks.

Air Canada has an NDT department consisting of one chief inspector and 12 NDT inspector/technicians who carry out radiographic, ultrasonic, and eddy current inspections. Canadian International Airlines NDT inspectors are all Level II.

850%
Growth Rate



64%
Growth Rate

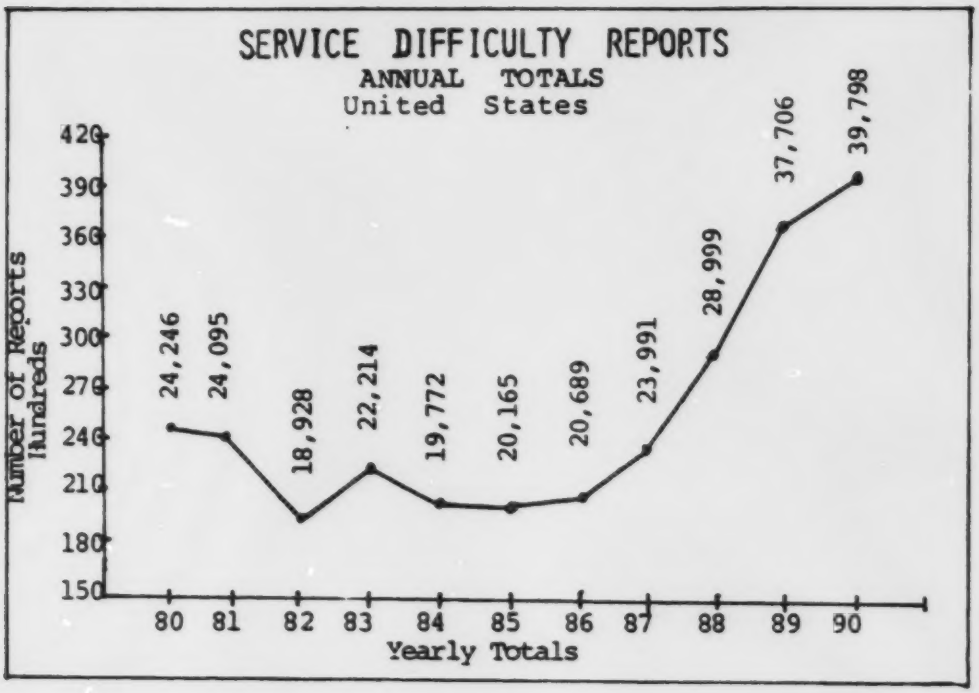


Table 9 - Comparison of total annual SDR reports

Many of the small commuter/regional carriers contract out their corrosion NDT to qualified local NDT organizations.

CARRIER	TYPE	NO.	AGE(YRS)
Air Canada	B-727-200	33	7 - 15
	B-747-100	3	15 - 18
	B-747-200	3	11 - 15
	B-767-200	20	0 - 7
	DC-8-60	2	19 - 20
	DC-8-70	6	19
	DC-9-30	35	15 - 22
	L-1011	12	8 - 16
Canadian	B-737-200	66	4 - 20
	DC-10-30	13	7 - 15
	L-188	2	30
	B-767-300	4	1
Wardair	Airbus 300	1	8
	Airbus 310	13	1 - 2
	B-747-100	3	17 - 18
	DC-10-30	1	11
		AVG. =	11.28

Table 10 - Age-Canadian air carrier fleet - March 1989

CARRIER	TYPE	NO.	AGE(YRS)	
Air Canada	B-727-200	28	10.8	
	B-747-100	3	17.3	AVERAGE =
	B-747-200	3	13.5	
	B-767-200	21	6.1	13 + yrs.
	DC-8-73F	6	20.8	
	DC-9-32	35	21.0	
	L-1011	14	15.0	
Canadian International	B-737-200	64	11.0	AVERAGE =
	DC-10-30	11	11.6	
	B-767-300	10	2.2	8 + yrs.
	Airbus 310	10	3.0	
		AVG. =	12.0	

Table 11 - Age-Canadian air carrier fleet - January 1991

			1989		1991
CARRIER	TYPE	NO.	AGE(YRS)	NO.	AGE(YRS)
Air Canada	B-727-200	33	7 - 15	28	10.8
	B-747-100	3	15 - 18	3	17.3
	B-747-200	3	11 - 15	3	13.5
AVG. 12.3	B-767-200	20	0 - 7	21	6.1
YRS. AGE	DC-8-60	2	19 - 20	--	---
	DC-8-70	6	19	6	20.8
	DC-9-30	35	15 - 22	35	21
	L-1011	12	8 - 16	14	15
Canadian	B-737-200	66	4 - 20	62	11.0
	DC-10-30	13	7 - 15	11	11.6
AVG. 6.9	L-188	2	30	---	---
YRS. AGE	B-767-300	4	1	10	2.2
	Airbus 310	0	1 - 2	10	3
		AVG. =	11.28		12.0

Table 12 - Age of fleets of major Canadian air carrier - March 1989 and January 1991

AIRCRAFT MANUFACTURER	AIRCRAFT TYPE	AIRCRAFT IN SERVICE	AVERAGE AGE IN YRS	
Boeing	707/720	235	21.8	
	727	1,682	16.3	% over avg.
	737(100/200)	1,048	11.7	age - 15 yrs. =
	737(300/400)	586	2.1	42.9%
	747	685	11.1	
	757	229	2.9	
	767	269	3.6	
McDonnell-Douglas	DC-8	279	21.6	
	DC-9	848	18.2	
	DC-10	369	12.8	
	MD-80	617	3.5	
Lockheed	L-1011	230	12.5	% under avg. age - 15 yrs. = 56.9%
TOTAL		7,077		

Table 13 - Average age of U.S. manufactured aircraft in worldwide use (as of July 1989)

AIRCRAFT MANUFACTURER	AIRCRAFT TYPE	YEAR 1989	1995	2000	
Boeing	707/720	197	232	235	1989 - 18.9% over 20 yrs.
	727	664	1,048	1,549	
	737(100/200)	201	380	634	
	737(300/400)	0	0	0	ESTIMATE 1995 - 33.6% over 20 yrs.
	747	4	242	448	
	757	0	0	0	
	767	0	0	0	ESTIMATE 2000 - 47.4% over 20 yrs.
Lockheed	L-1011	0	116	178	
McDonnell-Douglas	DC-8	242	279	279	
	DC-9	475	678	824	
	DC-10	0	200	322	
	MD-80	0	0	5	
Total		**1,783**	**3,175**	**4,474**	

Table 14 - Projected U.S. manufactured aircraft 20 years old or more in worldwide use for calendar years 1989, 1995, 2000

AGE IN YRS	# ACFT	PERCENT	
under 5	891	22.5	2,149 or 54.4% under 15 yrs.
5 - 10	680	17.2	
10 - 15	578	14.7	
15 - 20	556	14.1	1,797 or 45.5% over 15 yrs.
20 or older	1,241	31.5	
Totals	**3,946**	**100.0**	

Table 15 - Age distribution of U.S. airline fleet

o	1,800 AIRPLANES
o	59 DIFFERENT TYPES
o	17 DIFFERENT MANUFACTURERS
o	165 DIFFERENT OPERATORS

Table 16 - Commuter aircraft U.S.

-5	LOCKHEED L-1011s	15-17 YRS
-18	DOUGLAS DC-8s	19-26 YRS
-5	B-727s	18-24 YRS
-24	HS-748s	15-24 YRS
-32	CONVARS	32-37 YRS
-54	DOUGLAS DC-3	43-48 YRS

Table 17 - Selected Canada charter and regional airlines - June 1989
(15 years or more of age)

9. CANADIAN FLEET PROFILE

The number of registered aircraft in Canada totals 28,155 as of the 1990 census. This compares with a total of 294,955 registered aircraft in the United States. This represents a growth rate over the last ten years of 7 percent in the United States and 19 percent in Canada.

The United States commercial airline fleet totals about 3,671 aircraft and has an average age of 12.7 years. The Canadian commercial fleet averages about 12-plus years, with Air Canada fleet averaging between 13 and 14 years, and Canadian International with its newer Airbuses and B-767s, about 8-9 years.

The Canadian jet fleet, that is, the air carrier jet fleet, is made up of approximately 344 aircraft. One hundred and eleven of these are under 10 years of age; 78 aircraft are 10 to 15 years of age; 74 are 15 to 20 years of age; and 70 are 20 to 25 years of age. Only about seven are over 25 years of age. The average age of all these jet aircraft is about 11.6 years.

There are presently approximately just over 1,500 commercial aircraft in Canada with a gross weight greater than 4,500 kg (9,900 lbs.). The average age of these aircraft is approximately 25.76 years. This involves all aircraft used by fixed-base operators or commuter operators, as well as the two large air carriers.

10. COPING WITH AIRCRAFT AGING IN CANADA

10.1 Supplemental Inspection Documents (SID)

Service experience has demonstrated that there is a need to have continuing updated knowledge concerning the structural integrity of transport airplanes, especially as they grow older. This concern ultimately leads to the requirement for a structural reassessment or audit of these aircraft. SIDs have been developed to provide a continuing structural integrity program to ensure safe operation of older aircraft throughout their operational life. The SID is initially developed by the manufacturer for each model and is initiated whenever analysis and/or modification is necessary to maintain structural integrity. SIDs are an addition to the basic, complete maintenance program for the aircraft.

Transport Canada initiated a SID team after the Aloha accident. The team visited 18 Canadian air carriers that operated transport category aircraft and were affected by AD-mandated SIDs. Aircraft-aging items highlighted by this inspection were: (1) airworthiness authority approval is needed for all operators of transport category aircraft with AD/SID-affected repairs not addressed by the structural repair manual; (2) NDT is to be performed only by qualified, skilled personnel approved by the Canadian General Standards Board; and (3) the adequacy of any NDT accomplished in the United States is questionable because of poor standards.

10.2 Service Bulletins and Airworthiness Directives

A task force represented by numerous persons internationally, and associated with service bulletin revision has been reviewing fatigue service bulletins as well as corrosion service bulletins with a view to either terminating the bulletins or developing them into airworthiness directives. Boeing has already reviewed more than 700 such service bulletins on the Boeing fleet. McDonnell Douglas has reviewed more than 450 service bulletins, of which 140 will be terminated. The Lockheed working group reviewed over 250 bulletins and has recommended the termination of 40. These actions in the United States will affect Boeing, McDonnell-Douglas, and Lockheed aircraft in Canada.

Action by operators on service bulletins varies with airlines and ranges from 30 to 80 percent. That is, airlines frequently choose to continue inspections or perform local repairs rather than to terminate the bulletins. Many of the actions appearing in Figure 17 have already appeared in Notice Of Proposed Rule Making actions, which appear in the Federal Register. Others are contemplated as airworthiness directives for future aging aircraft, if not already converted to airworthiness directives.

o 727 - 74 Service Bulletins - 1,700 Airplanes World Fleet - Est. Final Rule AD Effective January 1990	o 737 Lap Splice Fastener Replacement - First 291 Airplanes - 100 U.S. Registered Airplanes - Total Cost/Airplane $80,000 - AD Effective May 8, 1989
o 737 - 58 Service Bulletins - 1,200 Airplanes World Fleet - $900,000/Airplane - Est. Final Rule AD Effective January 1990	o 727 Lap Splice Fastener Replacement - First 849 Airplanes - 623 U.S. Registered Airplanes - Total Cost/Airplane $58,000 - AD Effective August 21, 1989
o 747 - 31 Service Bulletins - 680 Airplanes World Fleet - $2,300,000/Airplane - Est. Final Rule AD Effective January 1990	o L-1011 - 39 Service Bulletins-Termination - 7 Service Bulletins-Inspection - 243 Airplanes World Fleet - Issue NPRM Est. December 1989
o DC-8 - 152 Service Bulletins - 346 Airplanes World Fleet - $18,620/Airplane - NPRM Issued September 14, 1989	o Recommendation from Model Task Group Review of Corrosion Program - Boeing 707/727/737/747 Issue NPRM Est. November 1989 - Douglas DC-8/9/10 Issue NPRM Est. February 1990 - Lockheed L-1011 Issue NPRM Est. March 1990 - Airbus A-300 Issue NPRM Est. March 1990 - Fokker F-28 Issue NPRM Est. April 1990 - Convair 580 Issue NPRM Est. March 1990 - British Aerospace BAC 1-11 Issue NPRM Est. March 1990
o DC-9 - 52 Service Bulletins - 920 Airplanes World Fleet - $76,100/Airplane - NPRM Issued September 14, 1989	o Recommendations from Other Model Task Group Service Bulletin Reviews - Airbus A-300 Issue NPRM Est. March 1990 - Fokker F-28 Issue NPRM Est. April 1990 - Convair 580 Issue NPRM Est. March 1990 - British Aerospace BAC 1-11 Issue NPRM Est. March 1990
o MD-80 - 22 Service Bulletins - 568 Airplanes World Fleet - $3,752/Airplane - NPRM Issued September 14, 1989	
o DC-10 - 33 Service Bulletins - 426 Airplanes World Fleet - $179,480/Airplane - NPRM Issued September 14, 1989	

Figure 17 - Service bulletin and airworthiness directive actions (Reference 4.)

Transport Canada is issuing 14 airworthiness directives on the DHC-6 Twin Otter. Ten are AD revisions to mandate terminating action, and four are being issued to mandate service bulletins. Transport Canada is also issuing 10 airworthiness directives concerning the Boeing deHavilland DHC-7 after a review of that aircraft's Aging Commuter Aircraft Program. Three of these are being mandated for terminating action, and 7 are being mandated for service bulletins. Both of these reviews were accomplished with the participation of the U.S. Regional Airline Association (RAA) and the Federal Aviation Administration (FAA) as well as Canadian operators (see Appendix E).

11. CONCLUSIONS

1. Accident and incident investigations concerning age-related aircraft structural failures have given valuable experience and knowledge in designing and building aircraft.

2. Aircraft aging conferences, symposiums and workshops permit the sharing of experience and views, as well as the development of solutions to the problem.

3. Inadequate maintenance compromises an aircraft's structural integrity.

4. Air carrier decisions to retire aircraft are usually concerned with marketplace considerations involving noncompetitive operating costs, excessive fuel costs, noise constraints, and noncompetitive performance and technology.

5. The Aloha accident served to arouse concern about the aircraft-aging problem.

6. The aviation industry should be committed to solving aircraft aging technical problems before political solutions are forced upon it.

7. The fail-safe concept of aircraft design used in the 1950s and 1960s is inadequate as aircraft approach and exceed their original economic life objectives.

8. The damage-tolerant concept of aircraft design will provide a "cradle-to-grave" total management plan.

9. The human factors aspects of aircraft aging dealing with human performance in maintenance and inspection need to be addressed in greater depth.

10. Aircraft airworthiness assurance lies with the interdependent responsibilities of the manufacturer, the operator, and the regulator.

11. The administration of Service Difficulty Reports has the potential for targeting those factors and conditions of aircraft aging that exceed established guidelines.

12. Airworthiness inspectors with a structural airworthiness background will greatly aid in the surveillance of aircraft that have exceeded their economic life objectives.

12. RECOMMENDATIONS

That an improved Service Difficulty Reporting system be set up for use in developing airworthiness directives; allocating aircraft, pilot and repair station inspection resources; developing trends, and identifying specific aircraft problems.

That aircraft maintenance engineer qualifying experience, training and licensing requirements be reviewed, with a view to employing more mechanics and inspectors with a structural airworthiness speciality background.

That the Canadian General Standards Board (CGSB), in coordination with Transport Canada and the Institute of Aerospace Research, develop standards and qualifications specifically for non-destructive inspection and testing certification in aviation, and require the Minister of Transportation to enforce these standards in civil aviation.

That Transport Canada continue to develop a heavy maintenance review team to perform regular hands-on sampling and spot-checking of various air carrier aging aircraft that are undergoing "D" or heavy maintenance checks.

That Transport Canada undertake and develop, with an international linkup, an SDR summary report equivalent to the U.S. FAA Service Difficulty Summary Report, and provide feedback to commercial operators in Canada.

That the Transportation Development Centre, in coordination with Transport Canada, research and develop a comprehensive human factors handbook for aviation maintenance and inspection technicians and managers.

That the Transportation Development Centre conduct a study of aircraft aging on rotorcraft in Canada.

That Transport Canada determine whether a Supplemental Structural Inspection program is needed for commuter aircraft.

That research be conducted to ascertain the reasons for errors in the maintenance environment.

That personnel of Transport Canada, the air carriers, and companies continue to participate in seminars and technical gatherings concerned with aircraft aging to exchange data.

That Canadian air carriers support Transport Canada's Service Difficulty Reporting program by reporting defects, failure, and malfunctions in order to ensure that required standards of safety are achieved and maintained.

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APPENDIX A

TRANSPORT CANADA

AGING AIRCRAFT ACTIVITIES STATUS REPORT

14 March 1990

TRANSPORT CANADA

AGING AIRCRAFT ACTIVITIES STATUS REPORT

1. BACKGROUND

On April 28, 1988, an Aloha Airlines Boeing 737 experienced an explosive decompression and structural failure at 24,000 feet, while on route from Hilo to Honolulu. Approximately 18 feet of the upper forward fuselage separated from the airplane during flight. A flight attendant was lost overboard during the decompression and several passengers and crew received serious injuries. The flight crew performed an emergency descent and landed on Maui.

The airplane had operated for 19 years, 35,000 flight hours and 89,000 flights in the marine environment of Hawaii. In terms of flight cycles, it was the second oldest B-737 in the world, and was operating well in excess of the Boeing economic design life, set at 75,000 flights. The fuselage failed along a skin splice as a result of fatigue cracks originating at many adjacent rivet holes.

The accident focused the attention of the world press on the problem of aging passenger carrying aircraft. It also raised the concern of airworthiness authorities, manufacturers and operators because the fail-safe design of the aircraft did not prevent the structural failure.

The Federal Aviation Administration (FAA) of the United States convened a Conference on Aging Aircraft in Washington, DC in June 1988. Following up on recommendations from the conference, the U.S. Air Transport Association (ATA) and the Aerospace Industries Association of America (AIAA) in cooperation with the FAA formed an Aging Aircraft Task Force to address aging problems for large passenger aircraft.

Transport Canada (TC) airworthiness engineers are participating in the working groups of the U.S. Aging Aircraft Task Force and the FAA airworthiness directives resulting from the Task Force activities are being implemented in Canada. In addition, TC is taking independent action on aging aircraft problems in Canada.

2. CANADIAN ACTIVITIES

2.1 Nondestructive Test (NDT) Regulatory Changes

On May 11, 1987, a 43 year old Douglas DC-3 operated by Northland Air Manitoba crashed near Pickle Lake, Ontario as a result of a wing structural failure. The accident investigation subsequently found that the wing had been inadequately radiographically inspected.

In view of these findings TC conducted a review of civil aircraft NDT procedures and

technician licensing. A report was issued in January, 1988, which recommended a number of measures to improve regulatory control.

The status of implementation of the recommendation is as follows:

Recommendation - adopt Canadian General Standards Board (CGSB) and military standards for NDT personnel qualification and certification, and regulate civil aviation NDT under the Approved Maintenance Organization structure.

Status - It is proposed that all NDT will be brought directly under the regulatory control of Transport Canada by amendments to the TC Airworthiness Manual to include this NDT as specialized work. This will require the NDT to be performed under the control of the appropriate maintenance organization with qualified NDT personnel subject to TC regulatory control. Consultation with industry is presently in progress.

Recommendation - upgrade the Aircraft Maintenance Engineer (AME) training curriculum and examination in NDT.

Status - The AME licensing system is under total review and re-construction. The curriculum has been increased by 300 hours. The NDT aspect of the curriculum is presently being negotiated. AME examination questions that deal specifically with NDT have been developed.

Recommendation - increase surveillance of AME NDT training.

Status - A program of auditing of the accredited community colleges involved in AME training is in process.

Recommendation - upgrade NDT training of TC airworthiness personnel.

Status - NDT training was provided for airworthiness personnel both in headquarters and regions in the last quarter of 1989.

2.2 Supplemental Inspection Program Implementation Review

Following the Aloha accident, a review team was formed and tasked to visit every Canadian air carrier with Supplemental Inspection Document (SID) affected aircraft to assess compliance with the SID requirements. The team completed their review of the 18 Canadian air carriers affected and issued their final report in December, 1988. They were able to confirm compliance with the SID requirements by all affected Canadian operators. The report produced is providing the basis for follow-on work.

2.3 Aging Aircraft Sampling Evaluation

In 1989 a program was initiated to survey the condition of older passenger aircraft in service in Canada, by visiting repair & overhaul facilities to observe older aircraft undergoing heavy maintenance. The objective is to obtain first hand knowledge of the condition of a sample of older Canadian aircraft, and to assess the maintenance systems that support them, in order to determine any corrective action required.

Two teams have been assembled and two visits were made in the last quarter of 1989. The first assessed a Convair 580 and the second a DC-9. The visits presently scheduled for this year are:

B737 - March
B727 - April
DC10 - May
HS748 - May

A report will be issued when the last visit is completed.

2.4 DHC-6/-7 Aging Aircraft Activities

The U.S. General Aviation Manufacturers Association (GAMA) and Regional Airline Association (RAA) in cooperation with the FAA convened a conference on Aging Aircraft in Kansas City in April, 1989. The conference included discussion sessions on a number of commuter airplanes, Including the Boeing deHavilland DHC-6 and DHC-7. Following the conference, GAMA and the RAA issued a Summary Report which included recommendations that:

- existing airworthiness directives (ADs) on all airplanes used in regional air carrier service be reviewed to determine if repetitive inspections need to be replaced by terminating actions;

- existing service bulletins (SBs) be reviewed to identify issues specifically relating to aging airplanes, with the intent of mandating compliance;

- corrosion manuals and related documents be prepared or updated; and

- Supplemental Inspection Documents be developed, issued and mandated by ADs.

Meetings were held with Boeing de Havilland (DHC) in the last half of 1989 to discuss application of the recommendations to the DHC-6 and DHC-7. Agreement in principle was reached for the development of an Aging Aircraft Document (AAD), addressing ADs and ABs, and a Corrosion Manual and SID for both the DHC-6 and DHC-7. The first AAD Review Meeting with representatives from DHC, operators, the FAA and TC is presently

expected to take place in the second quarter of 1990.

2.5 Canadair CL-44 Supplemental Inspection Document

At the request of TC, Bombardier Canadair have developed a SID for the CL-44 aircraft. An AD has been issued to mandate the SID.

2.6 Other Activities

Training for TC airworthiness inspectors on SIDs and corrosion control has been provided by a short course at the Transport Canada Training Institute in 1989.

An amendment to the TC Airworthiness Manual and an Airworthiness Manual Advisory to give TC the authority to require manufacturers to produce SIDs have been developed. Consultation with industry has been completed and the documents are ready for final approval and issue.

3. CONCLUSION

The commercial operation of aircraft whose age exceeds their original design objectives is likely to persist indefinitely. Much high profile work is being done by operators, manufacturers and airworthiness authorities world wide to improve the safety of operation of aging airplanes.

Transport Canada strongly supports these initiatives. Airworthiness directives resulting from U.S. Aging Aircraft Task Force activity are being implemented in Canada. In addition, TC is taking independent action to assess the condition of older aircraft operated in Canada, to ensure that Canadian regulations and maintenance systems adequately address older aircraft, and to work with Canadian manufacturers to facilitate the support of older Canadian manufactured aircraft.

March 14, 1990

APPENDIX B

TRANSPORT CANADA

AGING AIRCRAFT ACTIVITIES UPDATE

18 September 1990

TRANSPORT CANADA
AGING AIRCRAFT ACTIVITIES UPDATE

INTRODUCTION

Recent Transport Canada (TC) aging aircraft activities have concentrated in three areas:

1. Measures to improve regulatory control of aircraft nondestructive testing (NDT);

2. A review of older Canadian-operated passenger aircraft undergoing heavy maintenance, which we have called an aging aircraft sampling evaluation; and

3. A review of aging Canadian-manufactured passenger aircraft, in accordance with the recommendations of the Conference on Aging Commuter Aircraft held in Kansas City, USA, in April, 1989.

NONDESTRUCTIVE TESTING

On May 11, 1987, a 43 year old Douglas DC-3 crashed in Northern Ontario as a result of a wing structural failure. The accident investigation subsequently found that the wing had been inadequately radiographically inspected.

Canada has a system of certification of NDT technicians to standards of the Canadian General Standards Board (CGSB). Nevertheless, in view of the accident findings, TC conducted a review of civil aircraft NDT procedures and technician licensing. A report was issued in January, 1988, which recommended a number of measures to improve regulatory control. These recommendations have been adopted and are being implemented as follows:

TC REGULATION OF NDT

It is proposed that all NDT will be brought directly under the regulatory control of Transport Canada by amendments to TC airworthiness regulations to include it as "specialized work". This will require the NDT to be performed within the Approved Maintenance Organization structure with personnel qualified to CGSB or military standards and subject to TC regulatory control.

Consultation with industry is presently in progress. Drafting of amendments to the regulations is expected to begin this fall for issue in 1991.

MAINTENANCE PERSONNEL TRAINING

The NDT content is being upgraded in the curriculum of accredited community colleges involved in Aircraft Maintenance Engineer (AME) training. This is being phased into a total

review and re-construction of the AME licensing system. The AME training curriculum has been increased by 300 hours, a part of which is being allocated for additional NDT instruction. Negotiations with the colleges on the curriculum are expected to be completed this fall.

AME examination questions that deal specifically with NDT have been developed. A program of auditing of community colleges providing AME training has also been put into place.

TRANSPORT CANADA NDT EXPERTISE

Specialists in NDT have been staffed at TC airworthiness headquarters to provide expertise to headquarters and regional offices. An NDT training course has been provided for headquarters and regional airworthiness personnel.

AGING AIRCRAFT SAMPLING EVALUATION

A program to survey the condition of older passenger aircraft in service in Canada, by visiting repair & overhaul facilities to observe high time aircraft undergoing heavy maintenance was carried out between August, 1989 and May, 1990. The objective was to obtain first hand knowledge of the condition of sample of older Canadian aircraft, and to assess the maintenance systems that support them, in order to determine any corrective action required.

The aircraft surveyed were a Boeing 727, B-737, McDonnell Douglas DC-9, DC-10, Convair 580 and Hawker Siddeley 748. Most of the aircraft were in relatively good condition considering their age. The exception was the B-727, which had recently been imported, and was extensively corroded.

The final report of the Aging Aircraft Sampling Evaluation team included the following considerations and recommendations:

CORROSION CONTROL AND PREVENTION

It was noted that corrosion is a leading cause of structural failures and that there is a need for increased focus on corrosion. All operators reviewed stated that they had a corrosion control program; however, the programs were nothing more than corrosion work cards within the maintenance program. Moreover, in some cases the programs did not reflect the operating environment of the aircraft.

A recommendation was made for additional regulation requiring corrosion control and prevention programs to be mandatory, and separate and distinct from the maintenance program. It was proposed that the operational environment should be taken into account in addition to the aircraft age and cycles. There was also a suggestion that corrosion

control programs include information regarding the use of inhibiting compounds.

MAJOR REPAIR

It was noted that most operators do not have any guidelines to assess the fatigue performance of structural repairs, but rely instead on "good practice". Specific programs for re-inspecting repaired structures to ensure continued integrity are not in place. Also, multiple repairs were found in close proximity to one another on some aircraft.

It was recommended that repairs to primary structure be evaluated for fatigue and damage tolerance capability, and that inspection programs be established for repaired structure (FAR 25.571 amendment 45 standards). There was a further recommendation that Transport Canada ensure that operator's engineering staff are aware of existing repairs in the immediate area when designing additional repair schemes. Where multiple repairs in close proximity are unavoidable, the total structure should be evaluated for damage tolerance capability. It was also recommended that guidance material be developed to standardize repair documentation throughout the industry. Based on an observation that repairs to wing box structures seemed to be less numerous when compared to other aircraft structural areas, it was recommended that the effectiveness on wing inspection methods be reviewed.

NONDESTRUCTIVE TESTING

The operators visited have a broad range of NDT capabilities. Some have a large staff of CGSB certified personnel who perform all their inspections; others have essentially no NDT capability and contract out their NDT requirements. A concern was registered regarding inspections requiring liquid penetrants. One operator has CGSB certified personnel using fluorescent penetrants to stringent process standards; another operator has personnel with unknown training and no certification using red dye penetrants (the least sensitive).

It was recommended that Transport Canada establish a policy for the use of liquid penetrants concerning the acceptability of the less sensitive penetrants and whether or not CGSB certification is required. It was also stated that the capability of firms providing NDT services to the civil aviation industry should be monitored to ensure that the inspections are being performed as intended.

AGING IMPORTED AND LEASED AIRCRAFT

Specific inspection requirements were recommended for aging imported Transport Category aircraft. These inspections would fully take account corrosion aspects in conjunction with a review of Supplemental Inspection Documents (SIDs) service bulletins (SBs) and airworthiness directives (ADs) which relate to aging aircraft.

It was also recommended that a phased heavy maintenance program should not be authorized for an imported aircraft until it has undergone one block heavy maintenance check either in Canada or under TC surveillance. A limit was also proposed on the number of phases into which a heavy maintenance check can be divided.

It was recommended that aging leased aircraft be inspected or evaluated to ensure safety and airworthiness.

OTHER

It was noted that some operators may be considering elimination of a separate inspection department, with the inspection responsibility being placed on the mechanic. A very thorough review recommended of any request by a Canadian operator for authorization for such an arrangement.

A lack of refresher training for air carrier maintenance personnel was noted. Regulatory action is being taken to address this problem.

It was recommended that Transport Canada make itself more visible to operators, particularly where the maintenance of aging aircraft is involved. The need was also emphasized for Principal Airworthiness Inspectors (PAIs) to be trained on the aircraft operated by the air carrier to which they have been assigned. It was also recommended that PAIs receive training in human factors as they relate to aircraft maintenance.

Industrial safety matters including inadequate work stands and reluctance of workers to use ear defenders (hearing protection) were noted.

The recommendations of the report are being assessed. Implementation in each case is subject to funding considerations and, where applicable, industry consultation. Nevertheless, the objectives, i.e. providing first hand knowledge of a sample of older passenger aircraft in service in Canada and an assessment of the maintenance systems that support them, have been achieved.

CANADIAN AGING COMMUTER AIRCRAFT

The U.S. General Aviation Manufacturers Association (GAMA) and Regional Airline Association (RAA) in cooperation with the U.S. Federal Aviation Administration (FAA) convened a Conference on Aging Commuter Aircraft in Kansas City in April, 1989. The conference included discussion sessions on a number of commuter airplanes, included the Boeing de Havilland Division DHC-6 and DHC-7, which are manufactured in Canada. Following the conference, GAMA and the RAA issued a summary report which included the following recommendations:

- Existing airworthiness directives (ADs) on all airplanes used in regional air carrier

service should be reviewed to determine if repetitive inspections need to be replaced by terminating actions;

- Existing service bulletins (SBs) should be reviewed to identify issues specifically relating to aging airplanes, with the intent of mandating compliance;

- Corrosion manuals and related documents should be prepared or update; and

- Supplemental Inspection Documents (SIDs) should be developed, issued and mandated by ADs.

Following release of the conference report, Boeing de Havilland Division (DHC) were requested to organize airworthiness directive and service bulletin reviews. This was done, with the participation of operators, the FAA and Transport Canada. The DHC-6 AD/SB review was held on April 25-26, 1990. Ten ADs were selected for terminating action and four SBs were picked for AD action.

The DHC-7 AD/SB review took place on June $-5, 1990. Three ADs were recommended for terminating action and seven SBs were deemed to warrant mandating by ADs.

Transport Canada will take action this fall to issue the airworthiness directives and amendments recommended by the review. Boeing de Havilland have also been requested to develop Supplemental Inspection Documents and corrosion manuals for the DHC-6 and DHC-7 aircraft. Negotiations are continuing on this work.

CONCLUSION

The commercial operation of aircraft whose age exceeds their original design objectives is likely to persist indefinitely. Much high profile work is being done by operators, manufacturers and airworthiness authorities world wide to improve the safety of operation of aging airplanes.

Transport Canada strongly supports these initiatives. In addition, TC is taking independent action:

- to ensure that Canadian regulations and maintenance systems adequately address older aircraft (with particular emphasis on NDT);

- to assess the condition of older passenger aircraft operating in Canada; and

- to work with Canadian manufacturers to facilitate the support of aging Canadian-manufactured aircraft.

September 18, 1990

APPENDIX C

TRANSPORT CANADA

FINAL REPORT

AIR CARRIER SID COMPLIANCE

December 1988

FINAL REPORT

AIR CARRIER SID COMPLIANCE

SUMMARY

The Transport Canada (TC) Supplemental Inspection Document (SID) team has visited the eighteen Canadian air carriers who operate transport category aircraft that are affected by AD mandated SIDs. All operators are aware of the SIDs and stated that they are complying to the extent required of them. The SID team noted three major areas of concern:

1. the approval procedure for repairs not addressed in the Structural Repair Manual;

2. the implementation of the Nondestructive Testing requirements; and

3. the lack of SIDs at the Regional and District offices of TC.

INTRODUCTION

During the past few years, there have been a series of accidents/major incidents that have received considerable media attention and caused concern among the travelling public. The Aloha Airlines 737 accident occurred at the end of this series and intensified the need for the aviation industry and airworthiness authorities to address the requirements for assuring the airworthiness of older transport category aircraft. The FAA hastily convened a meeting of airworthiness authorities, aircraft operators and manufacturers, and other interested parties in Washington in early June 1988 for purpose of discussing and making recommendations concerning the future actions that must be taken to assure the airworthiness of older transport category aircraft.

During the past six years, Aircraft Manufacturers have developed Supplemental Inspection Documents (SIDs) specifying additional inspections in selected areas when aircraft usage passes certain thresholds (cycles/hours). As an interim measure, pending additional actions/requirements from the FAA or other airworthiness authorities, a team of air carriers operating SID affected aircraft to ensure that these inspections were being performed.

TRANSPORT CANADA ACTIONS

The Director, Airworthiness Branch, tasked Mr. S. R. Didrikson, Chief, Continuing Airworthiness to form a team of specialists to visit the air carriers to verify compliance with SID requirements. Specifically, the objectives of the team were to visit each air carrier operating aircraft affected by SIDs (for Boeing and Hawker Siddeley, Supplemental

Structural Inspection Document and for Fokker, Structural Integrity Program) for the purpose of:

1) confirming that the carrier is aware of the SID, has current issues of the SID, and is following the SID program;

2) discussing the SID with the carrier's personnel to determine how the SID requirements are integrated into the carrier's maintenance program; and

3) discussing any problems or other matter that the carrier may wish to mention.

The SID team members were:

Mr. Bohdan Goyaniuk	Structures Engineer
Mr. Ramon Raoux	Corrective Action Engineer
Mr. Charles Warren	Air Carrier Airworthiness Inspector

who visited each of the carriers listed below. In addition, Mr. Torck, Director Airworthiness Branch, Mr. Keith Walker, Superintendent, Structures Engineering, and Mr. Didrickson, participated in the Air Canada visit. Mr. Didrickson also participated in the Canadian Airlines and Wardair visits. The visits were not intended to be audits, but were made for an open exchange of information.

The emphasis initially was to visit the major air carriers. All air carriers with SID affected aircraft mandated by an AD were visited as indicated below:

Air Carrier	Affected Aircraft	Visit Date
Nationair	DC-8	June 20
Minerve	DC-8	June 23
Air Charter Systems	DC-8	June 23
Wardair	747	June 24
Air Canada	DC-8 & DC-9	July 05
Bradley/First Air	727 & HS 748	July 06
Canadian Airlines International	737	July 12
Time Air Inc	F28	July 13
Worldways Canada Ltd.	DC-8	Aug. 23
Air Ontario	F28 & HS 748	Aug. 24
Northlands Air Manitoba	HS 748	Sept 12
Calm Air	HS 748	Sept 13
Air Inuit	HS 748	Sept 28
Inter Canadian	F28 & 737	Sept 29
Amoco Canada Petroleum	HS 748	Oct. 04
Chevron Canada Resources	HS 748	Oct. 04
NWT Air	L188	Oct. 06
Air Creebec	HS 748	Oct. 02

SIDs for the Convair 580/640 and the DC-3 were issued during 1988; an FAA AD was issued in November 1988 mandating the Convair SID and AD mandating the DC-3 is anticipated in early 1989. SIDs are in preparation for the DC-10 and L-1011.

DISCUSSION

Approximately 2-3 hours were spent with each air carrier during the SID team visits. Representatives from the TC regional and/or district offices were invited to participate and did so for all but one visit. The SID team usually opened the meetings by informing the company personnel of the importance that TC puts on the SID program. Furthermore, it advised that the visit was not intended as an audit, but rather an open discussion with hopefully a free flow of information in both directions. The company personnel were then asked to brief the TC SID team describing how the SID requirements have been incorporated into the Maintenance Control Manual and maintenance programs and how the inspections were being performed. Subsequent to the briefings, there was usually a general discussion on the SID itself, including its ease of interpretation and any difficulties in complying with the inspection requirements.

Two particular concerns of the SID team were how the NDT requirements and non-SRM repairs are addressed. The large air carriers have in-house NDT groups staffed with CGSB certified NDT personnel having an aircraft background; hence they have no problem with the NDT requirements and should be performing the inspections properly.

Other operators do not have any NDT capability and have integrated the SID inspections into the "C" and "D" checks which are performed outside Canada; thus, they must rely upon these foreign maintenance facilities to provide competent NDT personnel. The USA has no national NDT standards for personnel certification and TC is aware that there are both highly competent and less than satisfactory personnel doing NDT in the USA; thus it is up to the air carrier's staff to be able to assess the maintenance contractor's NDT capability and take any necessary corrective action.

The regional air carriers have their own maintenance facility, but only have a limited NDT capability. They are contracting with NDT inspection firms having CGSB certified personnel for NDT services beyond their capability; however, this is not always a panacea for a lack of in-house NDT capability. Some SID programs are relatively inflexible; this does not offer operators the ability schedule NDT tasks, particularly when outside contractors are required. Pressure may develop to defer an AD item in order to avoid unnecessarily long times.

Despite the fact that radiographs are generally considered part of an aircraft's record set, some operators who contract-out for radiographic services are leaving their radiographs with the NDT firm, and in some instances do not even review them, merely accepting a written report.

There appeared to be some confusion over approval procedures to be used for inspection requirements developed as a result of repairs or modifications done to SID items discovered to be damaged following a SID inspection. Changes to inspection requirements may constitute an alleviation to the SID Airworthiness Directives.

A number of operators have repaired or modified a SID PSE after uncovering damage during their SID inspections. Some of these repairs have fallen outside of the SRM. Unfortunately, Transport Canada was not given the opportunity to review or approve the new inspection requirements as they related to the SID Airworthiness Directive.

FINDINGS & RECOMMENDATIONS

GENERAL

The air carriers have the relevant SID(s) and apparently are complying with the requirements. In some cases, they said that they are performing more than is required

or are performing the inspections sooner than required.

The air carriers are not having any problems interpreting the SID requirements and most are not finding these additional inspections to be too burdensome.

SPECIFIC

1. NON-SRM SID RELATED REPAIRS

   Inspection requirements may be affected by Non-SRM related repairs. Most carriers believe that a repair scheme issued by the aircraft manufacturer to correct damage related to a SID acceptable as is. Some even believe a carrier designed repair and a "No Technical Objection" from somewhere in the aircraft manufacturer's establishment constitutes a duly authorized repair scheme.

   RECOMMENDATION: An AMA should be prepared so that all operators of Transport category aircraft are cognizant of the need for an airworthiness authority approval of inspection requirements for all AD/SID affected repairs which are not addressed by the Structural Repair Manual (SRM). An ASI may need to be prepared to guide our personnel.

2. NONDESTRUCTIVE TESTING

   The SIDs specify extensive use of NDT, particularly eddy current and radiography. The aircraft manufacturers state that NDT is to be performed by qualified/skilled etc. personnel; this is interpreted as Level II of the national standard. Conversely, manufacturers of eddy current equipment claim that their equipment is so easy to operate and interpret; no training or experience is necessary. This rationale has been accepted by some of the regional air carriers.

   RECOMMENDATION: Implement the recommendations made in the December 1987 Transport Canada report **A STUDY OF NONDESTRUCTIVE TESTING IN CANADIAN CIVIL AVIATION**. This would be a large step in the correct direction in providing assurance that an NDT attributable accident does not occur in the future in Canada.

3. SUPPLEMENTAL INSPECTION DOCUMENTS

   With a few exceptions, the Regional and District offices do not have a copy of the relevant SID. Hence, they are not able to perform their surveillance/audit function on this aspect of the carrier's maintenance.

   RECOMMENDATION: The TC Regional and District offices should be provided with copies of the SID(s) for affected aircraft in their jurisdiction.

4. SID REPORTING

Except for Boeing, the manufacturers wish to be advised of the result of all SID inspections. Most carriers are complying. Some carriers thought "Nil Defect" reporting meant that only inspections which found defects were to be reported.

RECOMMENDATION: A letter should be sent to all operators of SID affected aircraft reminding them of this requirement and explaining the importance of the generated data.

5. MAINTENANCE/NDT IN USA

The general standard of maintenance on USA registered aircraft appears to vary considerably. There is no NDT standard in the USA that has been adopted by the aviation industry there; hence, the adequacy of any NDT done in the USA cannot be taken for granted without quality assurance safeguards.

RECOMMENDATION: The regions should be advised of these findings so that they will continue to see the need for thorough inspections of imported aircraft and ensuring the competency of foreign inspection/repair facilities with due regard for our Bilateral Airworthiness Agreement. Deficiences must be reported to the Chief, Airworthiness Inspection, so that the FAA may be advised so that corrective action can be taken by them.

6. MAINTENANCE CONTROL MANUAL

There is a lack of administrative procedures in some operator's MCM concerning the control of/compliance with airworthiness directives.

RECOMMENDATION: Regional Offices should be informed of this problem and they are to ensure MCMs state the administrative procedures pertaining to Airworthiness Directive control.

APPENDIX D

TRANSPORT CANADA

FINAL REPORT

AGING AIRCRAFT SAMPLING EVALUATION

September 1990

FINAL REPORT

AGING AIRCRAFT SAMPLING EVALUATION

SUMMARY

The Transport Canada (TC) Aging Aircraft Sampling Evaluation (AASE) team inspected six relatively high time Federal Aviation Regulation (FAR) 25 aircraft being operated in Canada during the August 89 - May 90 time frame. Although the purpose of these inspections was to sample the condition of six different aircraft types so as to get a "feel" for the possible condition of old aircraft in Canada, the Airworthiness Branch also wanted to assess what effect or responsibility the system (operator, manufacturer, airworthiness authorities) had on the condition of these aircraft and to determine if any regulatory action is needed to ensure the airworthiness of older aircraft in Canada.

The aircraft observed by the team that had been previously maintained in Canada appeared to be in a satisfactory condition considering their age (calendar time, flight hours, flight cycles); however, there are concerns for the condition of aircraft that have been maintained outside the country. This report describes a number of concerns that were noted by the AASE team; some of these concerns were reported previously in the Air Carrier SID Compliance Report issued in 1988. One of the many recommendations in the report is the Airworthiness Branch to continue evaluating aging aircraft.

INTRODUCTION

During the past few years, there have been a series of accidents/major incidents that have received considerable media attention and caused concern among the travelling public. The Aloha Airlines 737 accident occurred at the end of this series and intensified the need for the aviation industry and airworthiness authorities to address the requirements for assuring the airworthiness of older transport category aircraft. The importance of heavy maintenance/"D" checks and Supplemental Inspection Document (SID) requirements were recognized as key elements in ensuring the airworthiness of older aircraft. In 1988, TC sent a three man team to visit with operators of SID affected aircraft to get a verbal assurance that the operators were aware of the SID requirements and were complying.

The United Airlines Boeing 747 explosive decompression over the Pacific in February 1989 intensified the aviation world's attention to the aging aircraft issue. In early 1989, the Federal Aviation Administration (FAA) commenced a program to evaluate the fleets of U.S. manufactured aircraft operated by U.S. carriers during Heavy Maintenance (HM) checks. It was understood at the time that the initial emphasis by the FAA would be on Boeing products. It was the Airworthiness Branch's position that TC should commence a

sampling program to assess the condition of larger passenger carrying aircraft in Canada in a manner similar to that being done by the FAA. The objective was not only to complement the FAA's efforts by looking at aircraft that the FAA might not be looking at within the next one to two years, but also to continue the Airworthiness Branch's commitment to maintain surveillance on aircraft, so that the department can assure the Minister and the travelling public that aging aircraft in Canada continue to maintain their airworthiness. The aircraft that were thought to be suitable candidates were the HS 748s, Convairs and DC-8/9s plus selected B727/737s and F27/28s which were likely to exhibit the most wear and tear. By making six or seven visits to selected maintenance facilities in the August 89 - May 90 time frame, this sampling would enable TC to identify the tasks that must be initiated.

DISCUSSION

In early 1989, the Director, Airworthiness Branch (DAB) asked the Chief, Continuing Airworthiness to commence a sampling inspection of older FAR 25 category aircraft operating in Canada. The goal was for TC headquarters personnel to acquire an in-depth awareness of the likely condition of aging aircraft. The maintenance system was also to be reviewed. The follow-on objective was to substantiate the condition of the aircraft, i.e. what aspects of the maintenance system were attributable to an aircraft in remarkable (for its age) condition and what was lacking or inadequate that contributed to a deteriorated aircraft? The ultimate goal was to be knowledgeable so as to initiate necessary corrective action to ensure the continuing airworthiness of these older aircraft as they continue in revenue service. It was recognized that TC would not be duplicating the FAA effort, but complementing their program.

An Aging Aircraft Sampling Evaluation (AASE) team was formed comprised of a member (plus an alternate) from the Airworthiness Inspection, Continuing Airworthiness, and Engineering Divisions. Memos were sent to the Regional Directors advising them of the AASE team's creation and TC's objectives, and soliciting regional participation in the visits and assistance in the visit coordination. Letters were also sent to 28 aircraft operators in June 89 advising them of the AASE program and requesting that they submit their 1989/90 HM schedules to TC.

Although the operators were asked to respond within 30 days, most did not, and in many cases, responses were only obtained after written and verbal hasteners. The tardiness of the responses delayed the start of the program and affected the selection of the aircraft that were inspected. The AASE team eventually selected six aircraft to inspect, a Boeing 727 and 737, a Convair 580, a Hawker Siddeley 748 and a McDonnell Douglass DC-9 and DC-10. Five of these aircraft had been operated and maintained in Canada for at least the previous 10 years; one had been recently imported and all its maintenance had been performed outside Canada.

During the aircraft inspections, the following programs were assessed: maintenance, structural, SID, corrosion control and prevention, repairs, nondestructive testing and human factors. Some of the aircraft findings were recorded on film. The evaluation process associated with each aircraft required between five and ten working days at the operator's facility. Travelling, preparation, and report writing added to the time required for this program.

Visits commenced with a briefing to the operator (and Principal Airworthiness Inspectors (PAI) if available) to explain the purpose of the visit and to answer any questions about the AASE team's activities. During this briefing, the team emphasized to the operators that this visit was not an audit, but that if any serious infractions affecting airworthiness were noticed, the matter would be brought to the attention of the PAI for follow-up action as deemed appropriate. The team also emphasized that any reports produced would provide anonymity for the participating operators and, as such, the team was privileged to have very open discussions with the staff that they met. Prior to departing, a briefing was given to each operator indicating any major observations or concerns.

During the operator visits, the evaluation process included:

1. Inspecting the aircraft and documenting significant findings;

2. Reviewing the operator's and manufacturer's maintenance schedule;

3. Witnessing the aircraft inspection;

4. Reviewing applicable Airworthiness Directives (ADs), Service Bulletins (SBs), SIDs, corrosion control programme and the ability to comprehend and comply with the directions;

5. Reviewing the aircraft history and record; and

6. Interviewing personnel.

GENERAL OBSERVATIONS

The AASE team evaluated six aircraft, five of which were considered "aged" because of calendar age, flight hours, or flight cycles. Also, five of the six aircraft had been operated and maintained in Canada for the past 10 years; these aircraft were considered to be in a satisfactory state of airworthiness considering their age and operational history. One aircraft had been imported less than a year earlier; its condition was of concern to the AASE team (this matter will be discussed in more detail further in the report.)

The AASE team visits took place around the mid-point of the Heavy Maintenance (HM)

checks. On the basis of observations and discussions, the team concluded that inspection and maintenance personnel are being given sufficient time to perform their tasks in a thorough manner. It was mentioned that the pace of activity increases as the scheduled completion date approaches. Although this phase of a HM check was not witnessed, the team does not feel that airworthiness is being compromised. This conclusion is supported by the fact that some of the aircraft did not complete their HM check on schedule (i.e. scheduled operations did not take overriding priority).

The operators indicated that AD compliance (what must be done and when) can still be difficult to interpret, particularly if an AD is issued against a SB that has undergone several revisions and the operator has complied with one of the pre-AD revisions. Clarification of foreign ADs is usually obtained by contacting the Air Transport Association or the aircraft manufacturer. The airworthiness authorities are aware of the problem and of the need to write easily understandable directives. At the second FAA meeting on Human Factors titled, "Issues in aircraft Maintenance and Inspection", one recommendation was to get the lawyers and the "Legalese" language out of the AD process. TC shares the operator's concern about the difficulty in correctly understanding all aspects of an AD. In one instance, the TC Airworthiness Branch wrote to the Foreign Airworthiness Authority for a clarification of one of their ADs. The AD issuer had to staff the reply through the legal department and the written reply that came out did not provide any clarification. Later on the telephone, the AD writer acknowledged this fact and admitted the reply was the best that could be hoped for under the circumstances.

The SIDs contain additional inspections that apply to older FAR 25 aircraft. PAIs need access to the SIDs if they are to perform meaningful surveillance over the maintenance practices governing aging aircraft. The AASE team noted that the TC Regional and District Offices still do not have copies of SIDs for all of the SID affected aircraft in their region or district. This matter was noted in the 1988 Air Carrier SID Compliance Report. In many instances, the PAI is relying upon the operator to provide access to these important maintenance documents.

SPECIFIC OBSERVATIONS

1. <u>TRAINING</u>

   The need and desire for training, particularly refresher or update training, was a message that was stated by mechanics and inspectors associated with each of the facilities visited. The major carriers have formal training programs for apprentice mechanics which are designed to prepare the mechanics for their Aircraft Maintenance Engineer (AME) licensing exam and for endorsement exams. The other carriers visited have been able to hire sufficient numbers of mechanics with aircraft endorsements or to contract for endorsements courses. Once a mechanic has aircraft endorsements, the only training he could expect would be an inspectors course, if he worked for a major carrier and was becoming an inspector.

There has been some post endorsement training, primarily introductory courses when a carrier is introducing a new aircraft type to its fleet. A few mechanics/inspectors mentioned that they have attended an in-house seminar (few hours) on a specific piece of equipment or system; one mentioned having received a one week course on the efficient use of technical documentation Maintenance Manual (MM)/SID/Structural Repair Manual (SRM)/Illustrated Parts Catalogue (IPC)/AD/SB etc.) which he found extremely useful. However these examples have been the exception.

Some inspectors appear to not fully understand the effect that nicks, dents and scratches may have on the fatigue life of the aircraft structure. These defects may in some cases be left unattended even though, according to the SRM, rework or repair action would be required.

For many mechanics and inspectors, their last training session occurred at least 10 years ago. This training may have been an endorsement course on a -100 model of a given type of aircraft and the operator is now flying primarily -200 models. Also, there have been many changes/modifications to the operator's fleet over the years which the mechanics/inspectors may not always be aware of. The managements of all the facilities visited recognized the need for update/refresher training. However, it appeared to the AASE team that this training requirement was not considered a major concern. It was never stated that refresher training was going to be implemented because it has become an airworthiness manual requirement; the impression given was that the carriers now recognized as a need and had decided on their own volition to initiate refresher/update training.

2. AGING IMPORT AIRCRAFT

One of the evaluated aircraft had recently been imported along with two others. All three exhibited severe corrosion throughout. One of these (not evaluated by the AASE team) was refused a C of A due to the amount of corrosion found during the importation inspection. Had this aircraft not displayed visible signs of corrosion (i.e. skin pillowing, severe surface corrosion, etc.) it could have passed its importation inspection. The evaluated aircraft was due for a HM check within approximately 1000 flight hours. From a corrosion aspect, it was in poor condition and had been operated in an environment more severe than a Canadian operated aircraft would experience. The previous operator had used some corrosion control compounds on the aircraft. In those areas, there was a district lack of severe corrosion as opposed to the areas which did not receive any corrosion prevention treatment. The treated areas faired better, but still exhibited corrosion. During the HM for this aircraft, it seemed that the more one looked, the more corrosion that was found.

Several of the facilities that were visited indicated that they have also done HM work on foreign aircraft and described the state of disrepair that the aircraft were in. Some operators indicated that they could not always cope with their own HM work and

would contract out to a foreign overhaul facility; in such instances, nondestructive testing (NDT) was always a concern as these overhaul facilities frequently contracted for NDT and one Canadian operator felt the need to send its own NDT personnel to supervise this part of the HM.

TC has been examples of and been told of poorly maintained aircraft being imported into Canada. In many instances, the operator has committed to putting the aircraft into revenue service within a few days thereafter and been surprised when the TC PAI registered snags that required several weeks of unexpected maintenance. The recently imported aircraft that was observed by the AASE team was additional substantiation to justify TC's concerns about importing aging FAR 25 aircraft.

The AASE team concludes that the only way the structural condition of an aircraft can be assessed and necessary repairs can be conducted is during a HM check when all the insulation is removed.

3. CORROSION CONTROL AND PREVENTION

Corrosion management on large aircraft appears to rely primarily on the inspection tasks defined in the inspection work cards, and treatment and/or repair schemes provided in the aircraft structural repair manual. Products used for cleaning and lubricating the aircraft and those used for restoring corrosion protection are generally subject to an operator's approval process prior to authorization for use. Corrosion inspection requirements are adequately specified including the type of corrosion sought, the location and the applicable refurbishment procedures. There is, however, an absence of formal corrosion control programs incorporating specialist training and dedicated corrosion work cards. The concept of using a stand-alone corrosion control package based on a corrosion prevention and control manual is not new, however, the application of this concept seems to be judged impractical by operators.

There is evidence that effective corrosion control is being practised regularly on portions of the aircraft where corrosion problems have been identified. There are frequently other areas which do not get the full benefit of a thorough exploratory inspection for corrosion with the result that once a corrosion problem becomes evident a major re-build of the affected area is in order. This scattered approach ignores the fact that corrosion effects are closely related to aircraft usage conditions and, on aging aircraft, are likely to have developed to a detectable state if present. There is evidence that even when a problem area has been identified, the techniques used to monitor such areas are often restricted to general visual or, at most, detailed visual inspections. Special detailed inspections or use of a state-of-the-art NDT method or similar inspection aid is often ignored in spite of the fact that such an approach can make use of in-house capabilities or a regularly used NDT contractor.

All operators evaluated stated they had a corrosion control program; however, the

stated programs were nothing more than corrosion work cards contained within the maintenance program. Moreover, some of these programs were nothing more than a photo-copied version of the previous operator's program, with the current operator's name on the heading. The programs that have been copied from other operators in many cases do not reflect the new operating environment of the aircraft.

The most significant findings with regards to corrosion are:

- Corrosion programs do not recognize the significance of aircraft age;
- Corrosion varies significantly between operators and within an operator's fleet;
- Aircraft that are subject to a corrosion program from entry into service often can be relatively corrosion free;
- Repair activities are required every few years if corrosion program was only initiated after years service;
- Maintenance Control Manuals (MCMs) are inadequate regarding corrosion.

4. MAINTENANCE PROGRAMS

The FAA's Aircraft Certification Service Director, Mr. Craig Beard, at the recent Airworthiness Management Seminar in Singapore, has stated "An aircraft begins to age when it leaves the manufacturer. The whole maintenance program for aging aircraft is to maintain the original airworthiness certification. It takes on a different focus as the aircraft ages".

Most operator's inspection cards were found to be adequate in providing sufficient detailed information to accomplish the task. One operator's cards were inadequate in providing sufficient information to accomplish the task. Therefore, additional requirements should be considered with respect to addressing operator's inspection work cards to ensure that they are more than just adequate in providing information.

Inspection programs evaluated were not tailored to respect the unique aspects of an aging aircraft; for the most part, they treat aircraft the same. In certain cases, maintenance programs are photocopied from the previous operator of the aircraft. This practice has been around for years; however, it does not address the differences between operating environments or the uniqueness of aging aircraft. SSID programs and the new FAA ADs address aging aircraft; however, the basic maintenance program should be flexible to allow for change in age and any additional requirements, whether imposed by the manufacturer, regulatory authority, or in service experience.

A lack of thoughtfulness was evident during previous heavy maintenance inspections

as marker notes etc. were not always removed. This leads one to question whether the new markings have an impact on the present inspection or are the old markings confusing the issued.

Most operators inspection work cards were not cross-referenced to the basic minimum inspection criteria specified by the manufacturer in the Maintenance Planning Document (MPD). This made it extremely difficult and very time consuming to verify that all of the basic minimum inspections, as identified in the MPD, were being accomplished. Without such cross-referencing, it is possible that areas of the aircraft will not be inspected.

Multiple site damage occurring in older aircraft is of concern, and a number of aircraft evaluated had multiple site damage repairs. Aircraft operators should be cognizant of the need for increased inspections of these areas.

5. MAJOR REPAIRS

Structural repairs can degrade the fatigue and damage tolerance capability of primary aircraft structures; however, most operators do not have any guidelines to assess the fatigue performance of the repairs. They rely on "good practice" to account for the fatigue quality of the repairs. Specific programs for re-inspecting repaired structures to ensure the continued integrity of these repairs are not place.

Multiple repairs were found in close proximity to each other on some airplanes. This could impair the damage tolerance capability.

Some operators do not have a structural engineer staff and either rely upon the aircraft manufacturer or contract with a professional engineer to provide repair instructions. Although the aircraft (or fleet) is never seen by these personnel, this arrangement has served these operators well to date.

While reviewing MCMs it was noted that some operators have not updated these documents to reflect current procedures for major repairs and modifications. In effect, the MCM appears to be a document that must be developed for regulatory purposes but is subsequently not referred to by the operator. When reviewing repair records, it was noted, in some cases, that they did not reflect the approval data used for the repair and the description of the repair was insufficient. Furthermore, there was difficulty in tracing the repair records, especially when a change of ownership had taken place and when any SRM repairs which did not require engineering approval had been incorporated.

It appears that wing box structures have fewer problem areas reported when compared to other structural areas of the aircraft. Whether this is due to wings being over designed or to the fact that many areas of the wing are difficult to inspect could

not be determined.

6. INDUSTRIAL SAFETY

The major industrial safety concern is the inadequate of the work stands at some of the facilities visited. There were no railings and in some cases the steps were so steep that it was like climbing a ladder. These situations can best be described as an industrial accident waiting to occur.

The provision of safety equipment by the employer (ear defenders, safety glasses, protective clothing such as parkas and coverall) appears to be standard in the aircraft industry. Safety footwear is the only item not provided, but in most cases, the employees are subsidized for this item. One observation that concerned the AASE team is the reluctance of employees to use ear defenders. Much of the time there is a fairly high background noise level, but when riveting commences, the noise level becomes unbearable without ear defenders. Yet at each facility visited, some employees would continue working in close proximity to this noise source without putting on ear defenders. The effect of the high noise level on hearing will not be immediately apparent. At one facility, it was stated that the hearing of employees is tested every few years including upon the commencement of employment.

There does not seem to be too much enthusiasm for safety related matters by either management or workers. Most facilities had a safety committee; the employees generally were aware of its existence but were hard pressed to provide any details about its membership or activities. Those facilities that did not have a safety committee had individuals who took it upon themselves to perform the tasks. On the positive side, the need for first aid training was universally recognized. First aid boxes and fire extinguisher locations were easily noticeable, but fire extinguishers were sometimes missing.

7. SEPARATION OF PRODUCTION AND QUALITY

The inspectors, as part of the Quality Control Department, have two primary tasks during a HM check; to perform an initial inspection to determine the aircraft's condition and to assess the quality of any subsequent repair work. To ensure that maintenance quality is not sacrificed for operational requirements (through maintenance production). maintenance production and maintenance quality (inspections) are usually separate branches within a HM facility. The inspectors do not feel that their role is any more important than that of anyone else involved in HM. However, they do see themselves as the guardians of good quality maintenance standards and indicated that they have to exert their authority on a regular basis to ensure that maintenance/workmanship standards do not deteriorate. During the visits, AASE team members accompanied inspectors and saw examples of AME work, that was purported to be completed, but the inspectors still found the new work unacceptable. There could be many reasons

for these occurrences. Perhaps the mechanic just wanted to finish the task so that he/she could get another task, perhaps he/she planned to go home afterwards, or perhaps the mechanic thought the task was properly performed. It should be noted that at these stages of the HM checks, there would be no reason to believe that management would be pushing production nor were any of urgency noted. The inspectors also mentioned that there have been instances where management/production control has tried to save money or time by delaying repairs.

The inspectors at some of the facilities visited are concerned that their employer is considering the elimination of a separate inspection department and putting the inspection responsibility on the mechanic. The inspectors are generally the most experienced (and probably among the most capable) maintenance personnel. In such a scenario, some or many would revert to being crew chiefs or basic mechanics and there would be no concern about inspecting their own work. Some might leave the industry at a time when there are increasing demands for their experience and this action would not be condonable.

The immediate concern to TC is that many of the mechanics, though qualified and endorsed, have considerably less experience than the highly experienced inspectors who presently review their work. When one considers that days of work (weekday/weekend) and shift (day/night) are frequently decided upon union seniority (experience), some work shifts may have a large proportion of relatively inexperienced mechanics inspecting (and accepting?) their own work. Might some of this work be work that might be snagged by today's inspector?

8. NONDESTRUCTIVE TESTING

The operators that were visited by the AASE team have a broad range of NDT capabilities. Some have a large staff of Canadian General Standards Board (CGSB) certified personnel who perform all the operator's NDT inspections; others have essentially no NDT capability and contract out for their NDT requirements. One apparent concern that the AASE team observed applied to inspections requiring the use of liquid penetrants. One operator has CGSB certified personnel use fluorescent penetrants operating to stringent process standards; one operator has personnel with unknown (but likely very little) NDT training and no certification use red dye penetrants (the least sensitive of all penetrant types). Another operator has a CGSB certified individual who uses excessive amounts of red dye; the rationale was to assure management by the visibility of the dye residue after application of the developer that the inspection was actually done, but TC must ask how effective was the inspection due to the excessive amount of penetrant used. It was noted that one manufacturer does not produce NDT procedures to accompany its SBs. The SBs merely state the NDT method to be used. The other manufacturers provided NDT procedures but it was noted that occasionally better results can be obtained if these procedures are modified and in some instances, modification may be needed to get any meaningful

information. It would seem logical that NDT staff employed by an operator will modify/develop NDT procedures as required. The concern is whether a contracted NDT facility will do likewise or blindly follow the instructions provided.

The philosophy of applying NDT to aging aircraft appears to be no different than that of applying it to newer aircraft: Operators generally follow manufacturer's recommendation with respect to frequency of inspection, method used, inspection coverage, etc. There is little evidence that NDT inspections are established on the basis of how the aircraft is used or on its age unless known problem areas exist. Even then it is not common practice to improve NDT utilization. In many cases is perceived as an expensive tool although technological advances have reduced the cost of applying certain NDT methods. In particular, there is a reluctance to substitute the eddy current method of inspection for visual and liquid penetrant inspections.

9. TRANSPORT CANADA VISIBILITY

When the AASE team mentioned in their introductory briefing to the operators that their prime purpose was to inspect an aircraft and that it definitely was not an audit, they sensed that the operators were thinking "we've heard that one before" but were prepared to receive the team in line with this approach, at least initially.

The team was accorded access to all parts of the operator's facility and had the opportunity for unrestricted discussions with management and workers at the hangar floor level. After the team had spent a few days with the operator, the latter became convinced that the AASE team was there to do what it said it intended to do and not an audit.

During the many discussions that were had during the visits, it was strongly sensed that the operators were desirous of seeing a more frequent TC presence in a non-audit situation. If the inspectors or lower management have concerns that they feel the operator is not addressing, they see the PAI or other TC personnel as another agency to which their concerns can de addressed. It also provides an informal opportunity for operator/TC discussions on matters of common interest. Because of the openness of the discussions that were held, the task of the AASE team was made easier. A more frequent TC presence at the operator's facility would encourage an open flow of information, making TC more familiar with the maintenance activities, and permitting the PAI to catalyze changes/improvements using an indirect style of persuasion rather than by a more formal process. The operators realize that the PAIs have access to many maintenance organizations and thus have a diversified knowledge and experience. Hence any suggestions or recommendations from TC are likely based on workable examples found elsewhere.

CONCLUSIONS

Each accident/major incident involving aging aircraft likely will make headlines and receive or maintain the interest of the politicians and travelling public. Aging aircraft cannot be treated in the same manner as other aircraft, whether it be a transport category or commuter sized aircraft. The AASE team, comprised of staff in the TC Airworthiness Branch, was able to assess the condition of selected aging aircraft operating in Canada by inspecting six aircraft while they were undergoing HM checks. These inspections allowed the AASE team to determine the condition of these aircraft and to become aware of the problems associated with maintaining aging aircraft.

The aircraft inspected by the AASE team were operated by both major national carriers as well as by commuter and charter/second tier carriers. A major difficulty in selecting aircraft to inspect, was the scarcity of candidate aircraft, as many have HM checks performed over many phases. A DC-10, that could best be described as a "quasi" aging aircraft, was the only wide bodied aircraft that was undergoing a complete HM check during the time frame of interest to the AASE team. Older aircraft that are operating in Canada and were eligible candidates but were not selected for inspection include Fokker F27 and F28, McDonnell Douglas DC-8, Boeing 747 and Lockheed L188 and L1011 aircraft. Many DHC-6s, although much smaller than the other aircraft mentioned, are used regularly to transport passengers and are over 20 year old. Early production DHC-7s are now 15 years old. There are other old aircraft such as DC-4s and DC-6s that are used infrequently to transport personnel. There is also the DC-3 that is used more frequently. Furthermore, consideration has not been given to FAR 29 rotorcraft that transport passengers.

Looking at only six aircraft (6 different types) is too small a sample to say that aging aircraft operating in Canada are all in an airworthy condition. However, the AASE team did not see anything to suggest that such aircraft could be in an unairworthy condition. The aging aircraft that will be operated in Canada will be even older in the years ahead. There is no reason to believe that these aircraft will be replaced with newer types.

September 1990

RECOMMENDATIONS

1. TC should ensure that air carrier refresher/update training programs are initiated.

2. TC should review the contents of this training and ensure that the course material addresses the use of technical documentation.

3. TC PAIs need to be trained on the aircraft that they are expected to have airworthiness authority responsibilities for.

4. TC PAIs should receive human factors training so that they will be aware of the human factor issues and their effect on aircraft maintenance.

5. For imported FAR 25 aircraft which fit a Transport Canada definition of "Aging Aircraft", there should be specific inspection requirements before the aircraft can commence revenue operations in Canada unless TC is familiar with the aircraft's operational and maintenance history. These inspection requirements should be more in-depth in nature fully taking into account corrosion aspects in conjunction with reviewing supplemental structural inspection documents (SSIDs), structurally significant items (SSIDs), SBs and ADs which relate to aging aircraft. This should include a review of all previous heavy maintenance records, major repair records etc.

6. A phased HM program should not be authorized for an aircraft until it has undergone one block HM check either in Canada or under TC surveillance. In this regard, there should be a limit to the number of phases that a HM check can be divided into i.e. learn from Aloha.

7. Transport Canada should investigate the feasibility of establishing guidelines to setting up a comprehensive operator corrosion control program for aging aircraft including minimum requirements for training personnel in the inspection and treatment of corrosion.

8. There is a need for increased focus on corrosion, which should take into account not only the aircraft age and cycles but also the operational environment.

9. Corrosion is a leading cause of structural failures; therefore, additional requirements should be considered causing corrosion control and prevention programs to be mandatory, which should be separate and distinct from the maintenance program.

10. At present, the leasing of aircraft is on the rise; older aircraft may well be leased by a Canadian operator from a foreign source. These aircraft, should also be evaluated/inspected to ensure safety and airworthiness. One problem with this concept is the usual necessity by the lessee to operate the aircraft as soon as possible; any further inspections or requirements by TC would be an added burden and could delay their operations.

11. Corrosion control programs should also include information regarding the use of inhibiting compounds. Programs evaluated had no specific instructions regarding the use of inhibiting compounds, i.e. no instructions for their usage issued by the manufacturer or operator. Additionally, no safety precautions were provided.

12. Operator's work cards should be reviewed in conjunction with the MCMs to ensure that there is sufficient information to complete the tasks and to ensure that all maintenance programs/aspects are addressed.

13. Inspectors and mechanics should be reminded/educated on the need to remove marker notes after the necessary snag rectification action has been completed.

14. TC should investigate the feasibility of establishing guidelines for ensuring the inclusion of MPD items in or on work cards.

15. TC should ensure through acceptable means that operator's engineering staff are cognizant of repair in close proximity to one another when designing additional repair schemes.

16. All repairs to the principal structural elements (PSE) of an aircraft should be performed in accordance with FAR 25.571 amendment 45 standards. This means that all repairs to PSE's should be evaluated for their fatigue and damage tolerance capability. An inspection program including inspection method and inspection intervals should be established for the repaired structure.

17. Multiple repairs, in close proximity to one another, should be avoided. In cases of multiple repairs being found in close proximity to each other, the total structure in addition to each individual repair should be evaluated and scrutinized carefully for its damage tolerance capability.

18. Guidance material should be developed to standardize the repair documentation throughout the aircraft industry. Such guidelines should also address the keeping of complete records when aircraft ownership is transferred.

19. A review of inspection methods for wing box structures should be considered to confirm that there are no problem areas.

20. Transport Canada should closely monitor the course of actions for aging aircraft repairs developed by the FAA sponsored Airworthiness Assurance Task Force for the aging aircraft programs.

21. Where there are major safety deficiencies such as the quality of work stands, TC should try to persuade the facilities involved to take corrective action. These facilities have a TC "Approval" and in the event of a serious accident in this era of litigation, TC could be a party to any action for damages.

22. It is understood that the concept of mechanics inspecting their own work is in force at British Airways and KLM. If an application to TC is made to approve inspectorless maintenance, the matter should be carefully studied ensuring that separate comments from the present inspection staff are considered thoroughly.

23. Transport Canada should establish a policy for the use of liquid penetrants. Presently we cannot say whether the use of CGSB certified personnel using fluorescent penetrants represents overkill or uncertified personnel using dye penetrants is too low a standard for the civil aviation industry.

24. Transport Canada should monitor the capability of firms hiring and providing NDT services to the civil aviation industry to ensure that the inspections are being performed as intended.

25. Transport Canada should investigate the feasibility of establishing guidelines for introducing aging aircraft inspection criteria to supplement existing inspections.

26. Transport Canada should make itself more visible to the operators particularly where the maintenance of aging aircraft is involved.

27. An aging aircraft review program would increase the TC visibility in a positive way. This program could initially be addressed by informing the operators of the need for increased focus on corrosion programs and for providing corrosion inspections which are effective and provide the desired result. To further emphasize TC's concern regarding corrosion, the matter should be reviewed by the company PAI, to assist the operator in upgrading a current corrosion control and prevention program, or to assist in the development of one.

28. Aging aircraft will continue to be operated in revenue passenger service. The TC Airworthiness Branch should continue a program of evaluation selected aging aircraft including commuter aircraft so as to be knowledgeable enough to make or recommend corrective action, when required.

APPENDIX E

Airworthiness Directives Issued by

Transport Canada

BOEING CANADA DE HAVILLAND DIVISION DHC-6
SERVICE BULLETIN & AIRWORTHINESS DIRECTIVE REVIEW

On April 25 and 26, 1990, an Aging Commuter Aircraft Program airworthiness directive and service review was conducted on the DHC-6 Twin Otter aircraft at the Boeing Canada plant at Downsview, Ontario. Operators of DHC-6 aircraft as well as representatives of the U.S. Regional Airline Association (RAA), the Federal Aviation Administration (FAA) and Transport Canada (TC) participated.

As a result of the review TC is issuing 11 airworthiness directives as follows:

A. ADS revised to mandate terminating action

1. CF-73-03R1, Wing Spar Top Flange Cracking
2. CF-73-06R1, Control Cable Quadrant Cracking
3. CF-77-05R1, Elevator Control Loss
4. CF-78-17R1, Inter-rivet Cracking
5. CF-79-22R1, Fail Safe Feature in Flap System
6. CF-80-03R1, Elevator, Flap & Aileron Control Rods
7. CF-82-21R1, Elevator Root Rib Cracking
8. CF-83-11R1, Outboard Elevator Hinge Arm Assembly
9. CF-85-12R3, Aluminium Fitting Cracks
10. CF-87-02R1, Wing Spar Lower Cap Angles

B. AD issued to mandate service bulletin

11. SB 6/342, Chaffing of Upper Wing Strut

14 February 1991

BOEING CANADA DE HAVILLAND DIVISION DHC-7
SERVICE BULLETIN & AIRWORTHINESS DIRECTIVE REVIEW

On June 4 and 5, 1990, an Aging Commuter Aircraft Program airworthiness directive and service bulletin review was conducted on the DHC-7 aircraft at the Boeing Canada plant at Downsview, Ontario. Operators of DHC-7 aircraft as well as representatives of the U.S. Regional Airline Association (RAA), the Federal Aviation Administration (FAA) and Transport Canada (TC) participated.

As a result of the review TC is issuing 10 airworthiness directives as follows:

A. ADs revised to mandate terminating action -

1. CF-80-02R1, Cracks in Upper Drag Strut
2. CF-80-20R1, Cracks in Fatigue Test Airframe
3. CF-81-10R1, Failure of Wing Spoiler Spigot

B. ADs to mandate service bulletins -

4. SB 7-27-37, Flight Controls - Wing Flap Replacement
5. SB 7-53-15, Lower Flap Surface Cracking
6. SB 7-54-9, Inner Nacelles - Upper Longeron Strengthening
7. SB 7-57-11, Wing Forward Pick-Up Adaptor Plates
8. SB 7-57-12, Ground Spoiler Actuator Attachment Bracket
9. SB 7-57-14, Wing Inboard Leading Edge - Inboard Nacelle Joint Rework
10. SB 7-57-19, Wing Rear Mounting Adaptor Plates

14 February 1991

APPENDIX F

FIELD VISITS

OPERATOR	DATE
Transport Canada	3 Jan 1991
Air Canada	24 Jan 1991
Transport Canada	30 Jan 1991
Air Transport Asso. Canada	30 Jan 1991
Nationair Canada	1 Feb 1991
Field Aviation West	5 Feb 1991
Canadian Airlines International	5 Feb 1991
Time Air, Inc	6 Feb 1991
Canadian DOD	7 Feb 1991
Air BC	8 Feb 1991
Institute of Aerospace Research	11 Feb 1991
Transport Canada	11 Feb 1991
De Havilland Div. (Boeing)	14 Feb 1991
Worldways Canada	14 Feb 1991
Canadair	21 Feb 1991

Field visits were made to various organizations, carriers, and government agencies associated with aircraft aging. The visit critiques are on file with the Transportation Development Centre.

APPENDIX G

AIRCRAFT AGING CHECK LISTS

The following discussion areas were formulated for the purpose of stimulating interest in the many areas that can be addressed in planning for the long term concerning aircraft aging in Canada.

QUESTIONNAIRE ON AIRCRAFT AGING

Possible problem areas in aging aircraft:

1. More and more major maintenance is increasingly being done by non-airline repair stations; as a consequence, maintenance technicians are employed who may overlook discrepancies due to lack of familiarity with the airplane.

    a. May not be accomplishing structural repairs in conformance with Airplane Structural Repair Manuals (SRM).
    b. Blind fasteners may not be replaced with permanent fasteners as a result of reluctance by repair stations to report all findings in order to remain within contract budget.
    c. Cracks and corrosion may go undetected because repair station focuses on specific tasks in the contract.
    d. there may be a lack of documented technical data on the site such as service bulletins and technical information from the manufacturer.

2. Facilities should require permanent modification or replacement of certain parts rather than continued inspection. (Task Force decision).

3. How many aircraft are operating beyond the original design and test life for that aircraft?

4. How safe is "useful" aircraft life? Currently,"useful life" for currently operating aircraft is in the range of 25-30 years.

5. What kind of maintenance do air carriers perform now that will detect or defer aging of aircraft?

6. Do some airline mechanics fear pressure from the airline and therefore fail to report aging damage or cracks when seen?

7. An Aging-Aircraft Conference Report recently stated: "mechanics of limited experience are utilized to conduct the inspection of complex structures...and industry sampling results indicate that human inspection results vary from 60 to 80 percent accuracy." What can be done about this?

8. What are the latest technologies that are being used or developed for aircraft testing? Has the military already availed themselves of some of these new technologies? When can these new testing technologies be identified and effectively mandated for carriers?

9. What is the average age of the jet commercial fleet, now, and what will it be expected to be by the year 2000?

10. A recent Aging Aircraft Conference indicated that about 95 percent of the problems with aging aircraft are due to corrosion, and that "...corrosion control techniques are not adequately addressed in the present maintenance programs." Is this concern being addressed?

11. Is there a need for a comprehensive, high-cycle, airworthiness audit and review procedure for aging aircraft?

12. Should aircraft operators be required to justify the continued operation of aircraft that approach the high end of their design life?

13. It has been reported that jet maintenance costs rise about 2 percent a year. What has been your maintenance percentage of airline operating costs during the last 15 years (1975 to 1990)?

14. Because of varied national maintenance record-keeping standards of other countries concerning aircraft purchased from overseas, should certain maintenance records be required to be kept with aircraft for life?

15. Should "sunsetting" be implemented? That is, should federal certification of airplanes be terminated when an airplane reaches a certain age? Some of the original DC-8s and oldest B-747s have exceeded their original design goals.

16. Should some other criteria be used to determine aging in place of flying hours, pressurization cycles, and landings?

17. What would the absolute requirement of prohibiting the flying of airplanes 20 years or older in 1991 have on the Canadian commercial fleet? How many airplanes would be lost? ("Sunsetting")

18. Should the number of inspections of an aircraft be increased as the aircraft increases in age?

19. Should the flight-cycle service life of pressurized aircraft be established by a mandatory full-scale pressurization fatigue testing to duplicate twice the full-scale pressurization fatigue testing?

20. Should an effort be made to establish a maintenance and inspection program specifically for aircraft aging to present data for statistical and analytical purposes to better identify potential aircraft-aging problems?

21. If an aircraft-aging program is implemented in Canada requiring a stepped-up maintenance, repair, and inspection program, will there be sufficient airline and independent repair service capacity over the next several years to handle these increased demands?

22. What percentage of the repair facilities do the independent repair stations represent in Canada?

23. Has any study been made in Canada to determine whether the deicing process has had a detrimental affect on aircraft aging?

24. What has the Canadian Navy done, if anything, to prevent corrosion in aircraft used in maritime areas?

25. Has a study been made to determine whether various Canadian airlines differ in their maintenance procedures? (Aloha Air Lines had "D" checks spread out over a long period of time.)

26. Should a study be made to ascertain whether presently used chromate coatings, used in corrosion prevention, are in conflict with Environmental Protection Agency standards? Will the knowledge gained in the past 25 years concerning use of chromates be lost?

MANUFACTURER QUESTIONNAIRE - AIRCRAFT AGING

1. How many aircraft that you manufacture are operating beyond the original design and test life for that aircraft?

2. What has been your high-time aircraft and how has your design performed in older aircraft? Particularly with respect to--

   a. ease of maintainability?
   b. structural problem areas?
   c. structural performance evaluation?
   d. SSIDs?

3. Have initial airframe fatigue tests adequately "sheltered" aircraft in your fleet? If not, have new fatigue tests been implemented and have they developed new problem areas not discovered in service? What are they, if any?

4. Have you had a continuing in-service design evaluation as, for example, from operator reports? Or Service Difficulty Reports?

5. Have you had a program to evaluate the quality of repairs on your manufactured aircraft with a view towards removing repairs that do not meet requirements of damage tolerance?

6. One area of fatigue damage difficult to detect is multiple- site damage. What has been your experience with MSD?

7. On corrosion--have you made surveys to identify chronic areas of corrosion on older airframes, and do you have or plan a corrosion-control and prevention program?

8. On communications--in what ways have you acted as a focal point for providing timely recommendations for maintenance program revision?

9. Do the SIDs you publish clearly define their function, applicability, scope, and operator economic impact?

10. Have you or do you contemplate developing standard practice corrosion information and incorporating it into your maintenance manual?

11. In what industry task groups on aircraft aging have you participated?

12. Have you pursued a concept of tear-down of the oldest airline aircraft to determine structural condition and to conduct fatigue tests on these older aircraft?

13. Regarding Maintenance Planning Documents
    Structural Repair Manuals
    Overhaul Manuals
    Maintenance Manuals
    Corrosion Prevention Manuals
    Non-Destructive Testing Manuals--- Do these documents receive continual updating and therefore encompass newly-found problems and techniques?

14. Have you defined any fuselage or wing areas of high-time aircraft with the objective of identifying or locating possible future structural maintenance problems and, subsequently, providing advance information which will permit operators to plan and schedule appropriate actions as required?

COMPANY QUESTIONNAIRE - AIRCRAFT AGING

1. What NDI expertise is available to your company?

2. Have you had any recent specialized technical training for your NDI personnel?

3. Have you experienced rising maintenance costs in maintaining older aircraft? If so, please describe.

4. Where is corrosion a problem on your fleet of airplanes? Make? Model? Airframe locale?

5. When was the last time you had a regular tripartite meeting with the airworthiness authority and the manufacturer of your equipment, particularly with reference to aircraft aging?

6. Have you recently instituted any new maintenance procedures or any deviations in maintenance procedures in the past 3-5 years that might pose a risk to an aircraft's structure?

7. Do you think the maintenance process should stress the need for more detailed inspection, particularly on older aircraft?

8. If SIDs exist for your airplanes, have you found the damage expected during SID inspections?

9. Should operators be a party to developing SID programs? Have you participated?

10. Should a SID-type program be required for corrosion? Do you have one?

11. Do you or your mechanics ever decrease inspection intervals because of your experience with the equipment/product/airplane? Discuss.

TRANSPORT CANADA QUESTIONNAIRE - AIRCRAFT AGING

1. What have you done recently to improve information exchange?

2. Have you had any recent aging-fleet inspections?

3. Have you addressed the proposal to require fatigue testing of existing airplanes to two (2) lifetimes? Do you feel this is necessary? Why?

4. Do you encourage various operators to obtain and monitor the Service Difficulty Summary Reports?

5. Do you encourage periodic meetings between manufacturer and operator where you also participate?

6. Do you try to give consistent and standardized responses from all offices on any particular subject ?

7. Have you reviewed the corrosion-control techniques used today to determine if they are adequate for high-time airplanes?

8. Do the current Transport Canada certification criteria and maintenance practices adequately account for the continued use of high-time, high-cycle aircraft?

9. Is Transport Canada's surveillance of high-time, high-cycle fleet maintenance programs adequate to evaluate and to ensure that the airline's inspection and quality-control deficiencies are, if any, corrected?

10. Are Transport Canada inspectors sufficiently trained to recognize and deal with aircraft-aging questions such as lap-joint disbonding, corrosion, and multiple-site damage?

11. Have you sponsored any research into methods of detecting fatigue damage or into the nature of fatigue characteristics of older aircraft structures?

12. What industry task groups on aircraft aging have you participated in during the last several years?

APPENDIX H

LEASED AIRCRAFT BY AIRCRAFT TYPE

UNITED STATES

Table I - U.S. Registered Aircraft That Have Been Operated Overseas by Aircraft Type (As of March 1990)

Aircraft Type	Fleet Size	Number Operated Overseas	Percent Operated Overseas
Airbus A300	67	2	2.9%
A310	19	0	--
A320	6	0	--
Boeing 707/720	43	37	86.0
727	1,197	142	11.9
737	785	91	11.6
747	182	21	11.5
757	156	2	1.3
767	111	2	1.8
Douglas DC-8	200	134	67.0
DC-9	521	146	28.0
MD-80	407	8	2.0
DC-10	185	36	19.5
Lockheed L-1011	106	7	6.6
All others	140	26	18.6
Total	**4,125**	**654**	**15.9**

Source: Aviation Data Service

Table II - Leased Aircraft By Aircraft Type in the U.S. Fleet (As of March 1990)

Aircraft Type		Owned	Leased	Total	Percent Leased
Boeing	707/720	23	20	43	46.5
	727	666	531	1197	44.4
	737-100/200	177	236	413	57.1
	737-3/4/500	120	252	372	67.7
	747	93	89	182	48.9
	757	67	89	156	57.1
	767	47	64	111	57.7
Douglas	DC-8	118	82	200	41.0
	DC-9	280	241	521	46.3
	DC-10	117	68	185	36.8
	MD-80	159	248	407	60.9
Lockheed L-1011		52	54	106	50.9
All Others		96	136	232	58.6
Total		**2015**	**2110**	**4125**	**51.2**

Source: Aviation Data Service

Table III - Leasing History of a Late Model Boeing 737 (Serial Number 22453) (As of March 1990)

Operator	Timeframe	Country of Operation
Air Belgium	3/81 to 3/81	Belgium
Bahamasair	3/81 to 4/81	Bahamas
Air Belgium	4/81 to 4/81	Belgium
Eagle Air	4/81 to 4/81	Iceland
Britannia	4/81 to 11/81	United Kingdom
Eagle Air	11/81 to 11/81	Iceland
Air Belgium	11/81 to 10/82	Belgium
Orion Airways	10/82 to 10/82	United Kingdom
Air Belgium	10/82 to 3/83	Belgium
Wien Air Alaska	10/83 to 4/84	United States
Orion Airways	4/84 to 11/84	United Kingdom
IFLC	11/84 to 12/84	United States
America West	12/84 to 4/88	United States
Amberair	4/88 to 10/88	United Kingdom
Paramount Airways	10/88 to 11/88	United Kingdom
Dragonair	11/88 to 4/89	Hong Kong
Paramount Airways	4/89 to 10/89	United Kingdom
Dragonair	10/89 to present	Hong Kong

Source: Aviation Data Service

Table IV - Boeing 727 (Serial Number 21349)
(As of March 1990)

Operator	Timeframe	Counrty of Operation
Singapore Airlines	10/77 to 6/80	Singapore
Dan-Air London	6/80 to 11/81	United Kingdom
LACSA	11/81 to 4/82	Costa Rica
Dan-Air London	4/82 to 10/82	United Kingdom
LACSA	10/82 to 4/83	Costa Rica
Dan-Air London	4/83 to 10/83	United Kingdom
LACSA	10/83 to 4/84	Costa Rica
Dan-Air London	4/84 to 1/85	United Kingdom
Sun Country Airline	1/85 to 4/85	United States
Dan-Air London	4/85 to 12/85	United Kingdom
Sun Country Aitline	12/85 to 4/86	United States
Dan-Air London	4/86 to 1/87	United Kingdom
Sun Country Airline	1/87 to 4/87	United States
Dan-Air London	4/87 to 12/87	United Kingdom
Sun Country Airline	12/87 to 4/88	United States
Dan-Air London	4/88 to 12/88	United Kingdom
Sun Country Airline	12/88 to 4/89	United States
Dan-Air London	4/89 to 12/89	United Kingdom
Sun Country Airline	12/89 to present	United States

Source: Aviation Data Service

Table V - U.S. Registered Aircraft Operated Overseas by Aircraft Type and Location (As of March 1990)

Aircraft Type	Number	Location
Airbus A-300	2	Venezuela
Boeing: 707/720	9	Netherlands, Uruguay, Guyana, Peru, United Kingdom, Antigua, Dominican Republic
727	27	Colombia, Peru, Venezuela, Brazil, Costa Rica, Mexico, Bahamas
737	20	Zaire, El Salvador, Greece, Australia, Norway, West Germany, Guatemala
747	33	UK, New Zealand, Philippines, Netherlands, Lebanon, France, Japan, Switzerland, Singapore, Taiwan
757	1	West Germany
767	2	El Salvador, Colombia
Douglas DC-8	6	Liberia, Costa Rica, Zambia, Dominican Republic, Surinam
DC-9	3	Mexico, Guatemala
DC-10	15	Mexico, France, Zambia, Nigeria, Finland, Malaysia, Indonesia
MD-80	13	Argentina, Mexico, Netherlands, Antilles
Lockheed L-1011	6	Egypt, Ivory Coast, Bahrain, Trinidad
Others	2	South Africa
Total	139	

Source: Aviation Data Service